BRL

CONTRACT 169

REPORT NO. 1

UPPER ATMOSPHERE WINDS FROM GUN LAUNCHED VERTICAL PROBES

(Barbados, July 1964-August 1965)

SPACE INSTRUMENTS RESEARCH, INC.

BRL CONTRACT 169 REPORT 1

UPPER ATMOSPHERE WINDS FROM GUN LAUNCHED VERTICAL PROBES

(Barbados, July 1964-August 1965)

Prepared for

U. S. Army
Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland

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Approved by:

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Atlanta, Georgia

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INTRODUCTION

A continuing study of upper atmospheric winds over the lower West Indies has been made possible by the firing of high altitude ballistic probes from a sixteen-inch gun located on the Island of Barbados. These firings are being carried out by the U. S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, under the direction of Dr. Charles H. Murphy, and by the Space Research Institute of McGill University, Canada, under the direction of Dr. G.V. Bull.

Atmospheric winds are studied by releasing chemical trails from the gun fired probes during the upper portion of their trajectories. To date, the primary chemical which has been released is trimethyl aluminum (TMA). TMA produces a chemiluminescent glow in regions of the atmosphere above 85 kilometers, thus allowing the trails to be photographed while being distorted by upper atmosphere winds. The photographs can then be reduced by Space Instruments Research using computer techniques to provide wind information.

Although the data reduction given in this report is funded directly by the U. S. Army, it is part of a joint U.S.-Canadian HARP-McGill program which is supported by the U. S. Army and the Canadian Department of Defense Production.

The purpose of this report is to summarize results of these studies for the period from July, 1964, through August, 1965.

DATA ACQUISITION

The chemical trails are formed almost vertically over the island of Barbados (longitude 59.4°W, latitude 13.0°N) and extend from an altitude of 85 kilometers through apogee. In some firings, TMA is also released on the down leg of the trajectory. To the unaided eye, the chemical release first appears as a straight white trail resembling a jet contrail. Within a minute or so, the trail is distorted into strange shapes by the upper atmospheric winds, and fades from view within fifteen minutes after initial release.

Space Instruments Research has established eight photographic triangulation stations on the islands of Barbados, St. Vincent, Grenada, and Tobago, with two sites per island. Sites were also located on St. Lucia during one of the earlier series. These islands are located to the west and south of Barbados at distances of 190 to 290 kilometers. While only one site on each of two islands is needed for data reduction purposes, the eight sites have been found necessary because of cloud conditions in the area.

Equipment at each site, built by SIR, consists of a camera unit containing two seven-inch focal length cameras mounted on a concrete pedestal and an electronic camera control. Cameras are automatically pulsed to take exposures of 3, 6, and 12 seconds duration every thirty seconds.

Since commercial power is either unreliable or unavailable at most site locations, SIR has developed a battery operated 115-volt power supply for the control equipment. The power supply is tuning-fork controlled and provides 60 cycle power with an accuracy of 0.005%

for the camera programmer so that pictures can be taken simultaneously at each site. A data chamber on each camera unit records time as well as shot and site information in the corner of each frame of film.

A short wave radio net connecting all sites and the launch control center has been installed by SIR to enable the launch control officer on Barbados to be informed of weather conditions on the islands and to synchronize picture-taking operations with the firing of the gun. Most sites are operated by local personnel, trained by SIR.

During a typical night's operation, the gun is fired at one to two-hour intervals, weather permitting, from sunset to sunrise. Photographs are taken by all sites while the trail is visible. The film is returned to Atlanta for processing and data reduction.

DATA REDUCTION

Upper atmospheric winds are determined by means of several computer programs from measurements taken from pictures of the trails.

As the method used is basically three dimensional triangulation using spherical trigonometry, it is necessary to know precisely the direction each camera was pointed during a given firing. The direction is determined by first taking accurate measurements of the locations of several star images on the film and then computing the azimuth and elevation of the optical axis of the camera by means of a computer program, making use of the celestial coordinates of some 6,000 stars which have been stored on magnetic tape.

Wind speeds and directions are then determined from the location of the trail in space at a succession of known times. The location is found using either a point position or trail position program or both and depends on the nature of the chemical release.

Point location method. If the chemical release exhibits discrete points (resulting either from turbulence or from the nature of the release mechanism) and these points can be identified on films from two or more islands, the point location program can be used to calculate the position of each point in longitude, latitude, and altitude above sea level from measurements taken from the films. These calculations are made from data taken at successive times. A wind program can then calculate both vertical and horizontal winds from the motion of these points as a function of time.

Trail location method. Most of the chemical releases produce a smooth trail having few, if any, identifiable points. In such cases,

film coordinates of a large number of incremental points along the film image of the trail are fed into the computer from data from two or more islands. The trail location program attempts to triangulate each point from one site with many points from another site, finally choosing points from both sites whose optical paths from camera into space form the closest spatial intersection. After doing many hundreds of such calculations, the computer is able to construct coordinates for a mathematical curve in the shape of the trail in space. Then, as with the point location program, winds can be determined from the motion of the curve with time. Here, however, it must be assumed that vertical winds are essentially zero. This assumption is borne out by previous studies which have shown vertical winds in this altitude region to be of the order of a few meters per second compared to horizontal winds ranging up to 150 meters per second.

Corrections for such variables as atmospheric refraction, rotation of camera about optical axis, and camera focal length variations are incorporated into the programs to maintain high accuracy. Focal length and camera rotation are in fact calculated from measurements of the positions of star images on the films.

INTERPRETATION OF DATA

The remainder of this report presents the results of wind studies from eighteen shots. For each shot, results are first shown in tabular form, followed by plots of wind velocity, heading, components, and shear.

In nearly all cases, winds were calculated at altitude intervals of one kilometer. Points on the various plots show the actual computed results as listed in the table preceding the plot. A curve has been fitted to each set of points to aid in detecting wind patterns and to indicate reliability of the plotted results. Each curve has been drawn with a knowledge of intermediate results leading to the wind calculations and of the consistency of the winds as calculated between each of the five or six time intervals used. In cases where point-to-point curve fitting was not thought to reflect actual variations in wind velocity, heading, components, or shear, a more appropriate smooth curve has been drawn. Otherwise the curves are fitted directly to the data points. Results of certain portions of the trails are at times less accurate than others due to the spacial orientation of those trail segments relative to the available photographic stations. Less accurate data also can result from photographs obscured by haze and clouds and from trails of short duration.

Wind velocity plot. This plot shows the velocity of the wind vector in meters per second as a function of height in kilometers above sea level.

Wind heading plot. The wind vector is considered to point in the direction toward which the wind is moving. The heading plot shows

the direction of this vector in degrees clockwise from north as seen from above. Thus a wind heading toward the east would be ninety degrees.

Wind components plot. While plots of wind heading and velocity do completely describe the wind vector, it has been found helpful in studying wind patterns to present the north-south and east-west velocity components of the vector. In the north-south plot, north is positive; south is negative. In the east-west plot, east is positive, west negative. Components are plotted in meters per second versus height in kilometers.

Wind shear plot. Of considerable interest in upper atmospheric wind studies is the wind shear, or rate of change of velocity with altitude. Shear is plotted in component form showing north-south and east-west shears in meters per second per kilometer versus height in kilometers. The shear components are not listed in tabular form as they are calculated from the curves fitted to the plots of wind velocity components rather than from the points themselves. This approach was found necessary to provide realistic values of wind shear.

TABLE OF TRAIL INFORMATION

Trail No.	Name	Date	Time (AST)	Altitudes (Km)
1	Iris	7 July 1964	19:02:29	94-102
2	Janet	7 July 1964	21:10:00	87-95
3	Sharon	22 July 1964	19:00:00	95-98
4	Quennie	24 July 1964	19:45:00	90-96
5	Lupaca	23 March 1965	21:24:03	92-114
6	Miami	24 March 1965	01:03:00	101-110
7	Nootka	27 March 1965	02:20:00	92-111
8	Ottawa	28 March 1965	20:01:50	105-119
9	Pueblo	28 March 1965	22:20:00	90-117
10	Marius	3 June 1965	19:57:00	102-114
11	Nero	3 June 1965	22:41:00	88-94
12	Elagabulus	4 June 1965	01:34:56	91-121
13	Fabius	4 June 1965	03:17:00	92-107
14	Ovid	9 June 1965	21:57:00	95-103
15	Cicero	9 June 1965	23:57:50	91-103
16	Pliny	10 June 1965	21:07:00	97-108
17	Tiberius	5 August 1965	20:20:30	95-107
18	Umbria	6 August 1965	02:44:00	94-106

SECTION I

FOUR TRAIL RELEASES July 7-25, 1964

SHOT IRIS 7 JULY 1964 19-02-29 AST

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
94.0	132.7	47.2	-32.0	34.7
95.0	150.0	61.8	-53.5	30.9
96.0	165.6	69.9	-67.7	17.4
97.0	178.1	85.4	-85.4	2.8
98.0	198.1	85.4	-81.1	-26.5
99.0	213.6	78.9	-65.7	-43.7
100.0	224.9	59.1	-41.8	-41.7
101.0	247.3	42.8	-16.5	-39.5
102.0	283.2	35.4	8.0	-34.4

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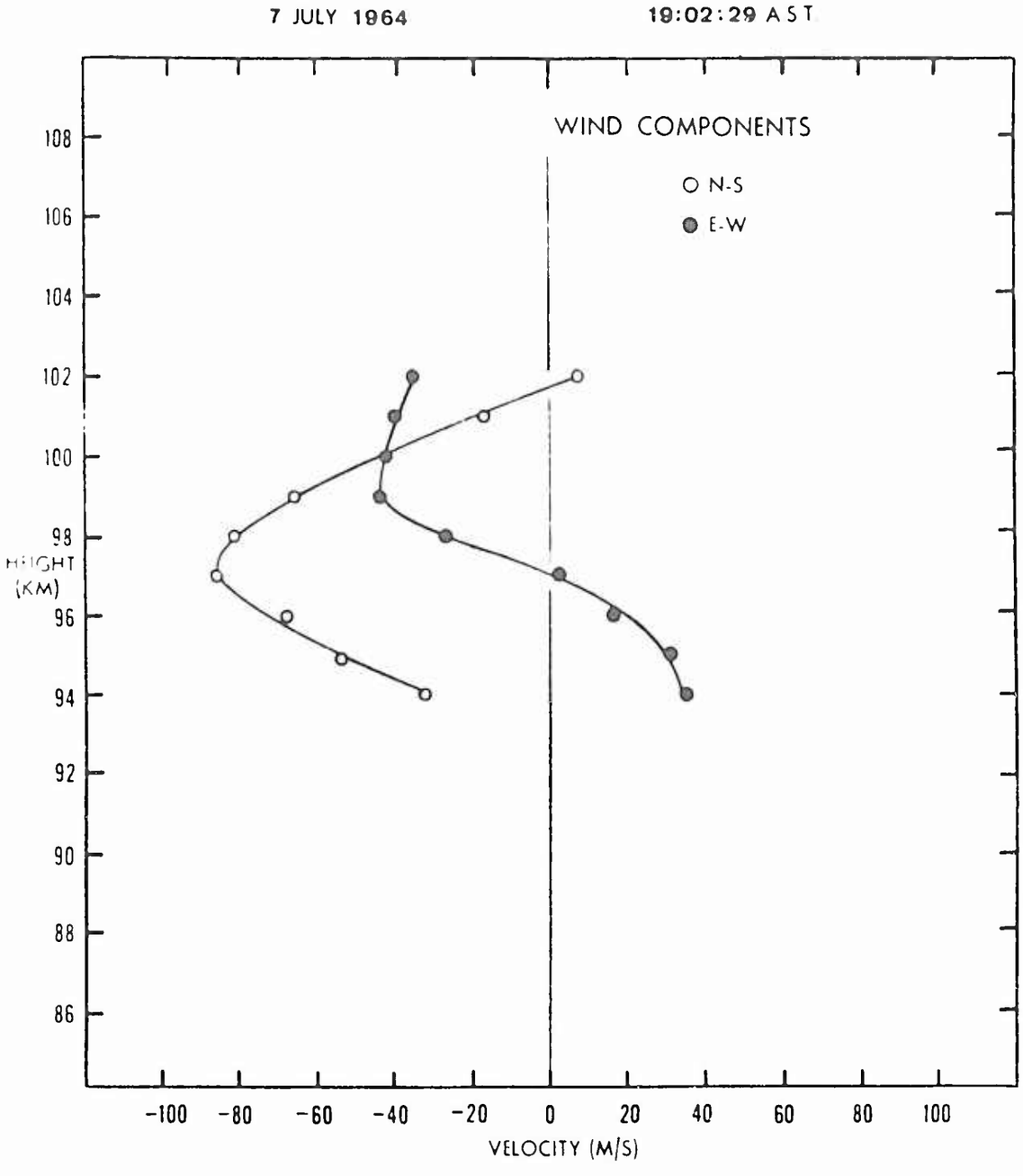
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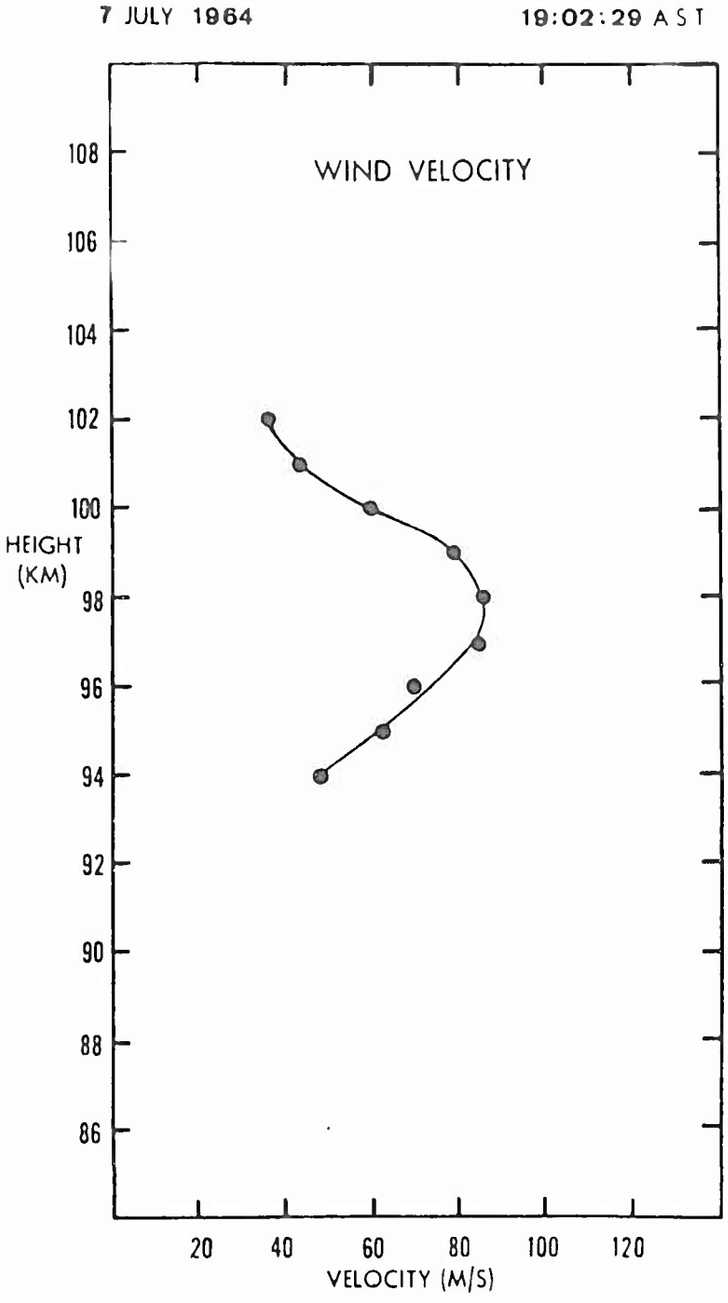
19:02:29 AST
WIND COMPONENTS
O N-S
E-W
108
106
104
102
100
98
96
94
92
90
88
86
HEIGHT (KM)
-100
-80
-60
-40
-20
0
20
40
60
80
100
VELOCITY (M/S)

IRIS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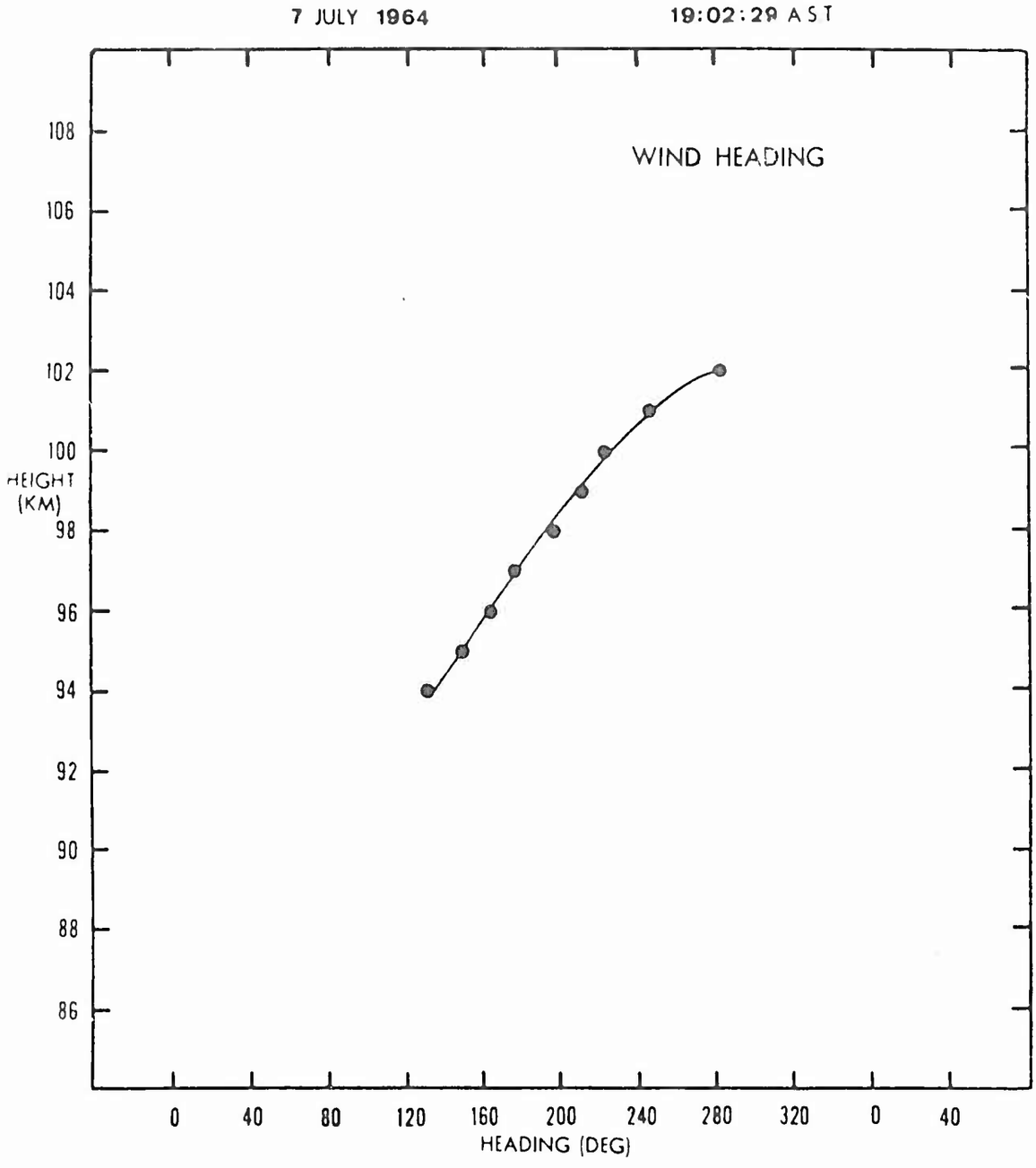
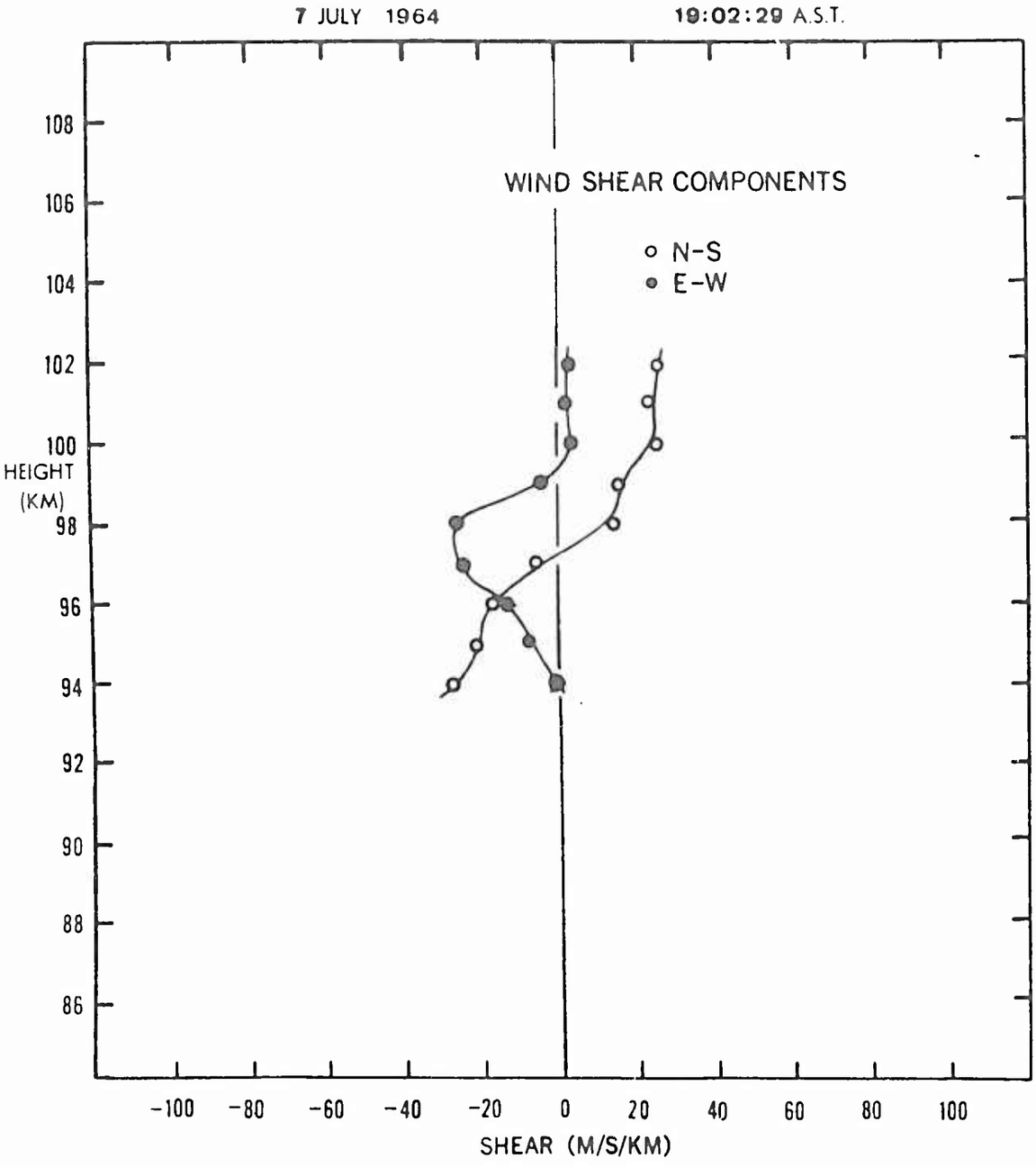
19:02:29 AST
WIND VELOCITY
HEIGHT (KM)
108
106
104
102
100
98
96
94
92
90
88
86
20
40
60
80
100
120
VELOCITY (M/S)

IRIS


7 JULY 1964
19:02:29 AST
WIND HEADING
108
106
104
102
100
98
96
94
92
90
88
86
HEIGHT (KM)
0
40
80
120
160
200
240
280
320
0
40
HEADING (DEG)

IRiS


7 JULY 1964
19:02:29 A.S.T.
WIND SHEAR COMPONENTS
N-S
E-W
HEIGHT (KM)
108
106
104
102
100
98
96
94
92
90
88
86
-100
-80
-60
-40
-20
0
20
40
60
80
100
SHEAR (M/S/KM)

SHOT JANET 7 JULY 1964 21-10-00 AST
UP TRAIL

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
87.0	117.3	28.1	-12.9	25.0
88.0	121.2	12.3	-6.4	10.5
89.0	119.6	18.7	-9.3	16.3
90.0	86.9	13.9	0.7	13.9
91.0	118.2	15.0	-7.1	13.2
92.0	138.7	30.6	-23.0	20.2
93.0	138.3	46.2	-34.5	30.7
94.0	141.9	60.3	-47.4	37.2
95.0	138.9	71.5	-53.9	47.0

SHOT JANET 7 JULY 1964 21-10-00 AST
DOWN TRAIL

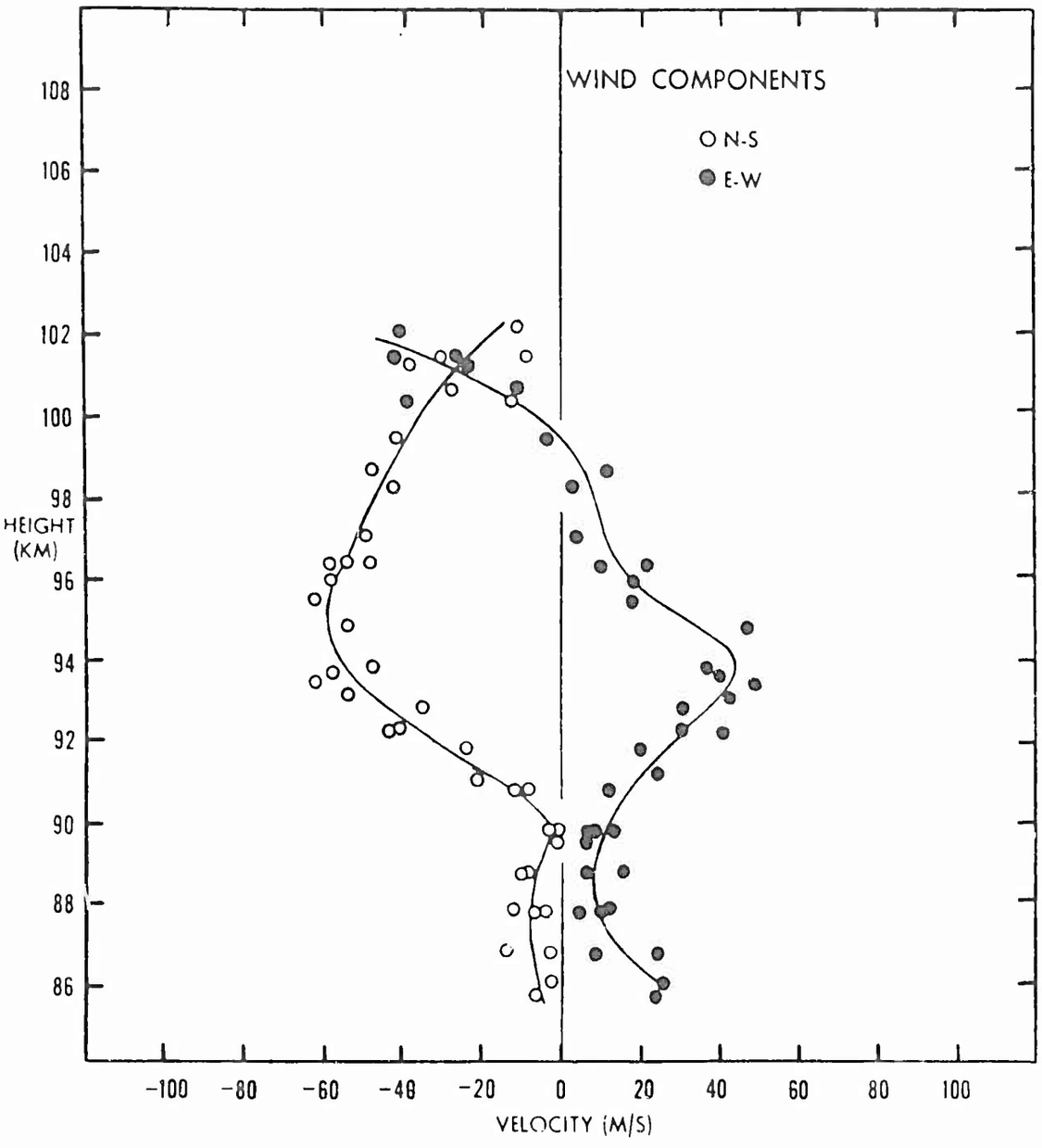
ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
86.0	102.9	25.6	-5.7	24.9
87.0	100.6	9.2	-1.7	9.0
88.0	122.0	6.2	-3.3	5.3
89.0	137.0	10.5	-7.7	7.1
90.0	109.2	7.3	-2.4	6.9
91.0	131.8	16.8	-11.2	12.5

SHOT JANET 7 JULY 1964 21-10-00 AST
POINT MOTION

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
93.8	145.0	70.4	-57.7	40.4
91.2	129.3	32.1	-20.3	24.8
97.2	175.3	49.2	-49.0	4.0
98.8	166.6	49.2	-47.8	11.4
98.4	176.0	42.1	-42.0	2.9
96.5	170.4	59.6	-58.7	9.9
95.6	163.9	64.8	-62.3	18.0
100.8	202.1	29.3	-27.2	-11.0
101.6	221.3	39.8	-29.9	-26.2
99.6	185.0	42.0	-41.8	-3.6
102.2	255.0	42.0	-10.9	-40.5
100.5	252.6	40.4	-12.1	-38.6
101.4	211.3	44.6	-38.2	-23.2
96.5	168.2	49.2	-48.1	10.1
86.3	93.3	26.7	-1.5	26.6
90.0	106.9	9.1	-2.6	8.7
88.1	131.2	17.0	-11.2	12.8
89.7	93.2	7.0	-0.4	7.0
101.6	258.5	43.3	-8.7	-42.4
96.5	158.4	58.4	-54.3	21.5
96.1	162.3	60.7	-57.9	18.5
93.6	141.5	78.5	-61.5	48.9
93.3	141.7	67.8	-53.2	42.1
92.5	142.4	51.0	-40.4	31.1
92.4	136.0	59.3	-42.7	41.2

JANET

7 JULY 1964 21:10:00 A S T.



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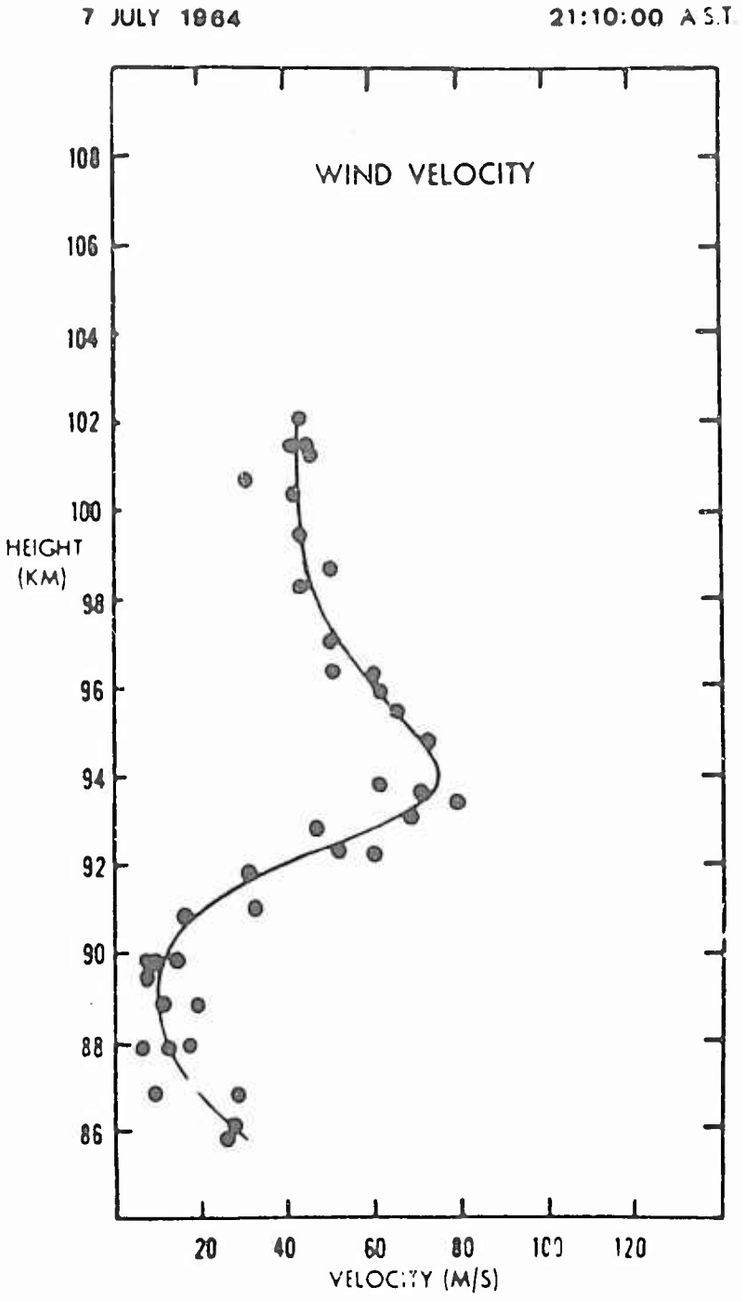
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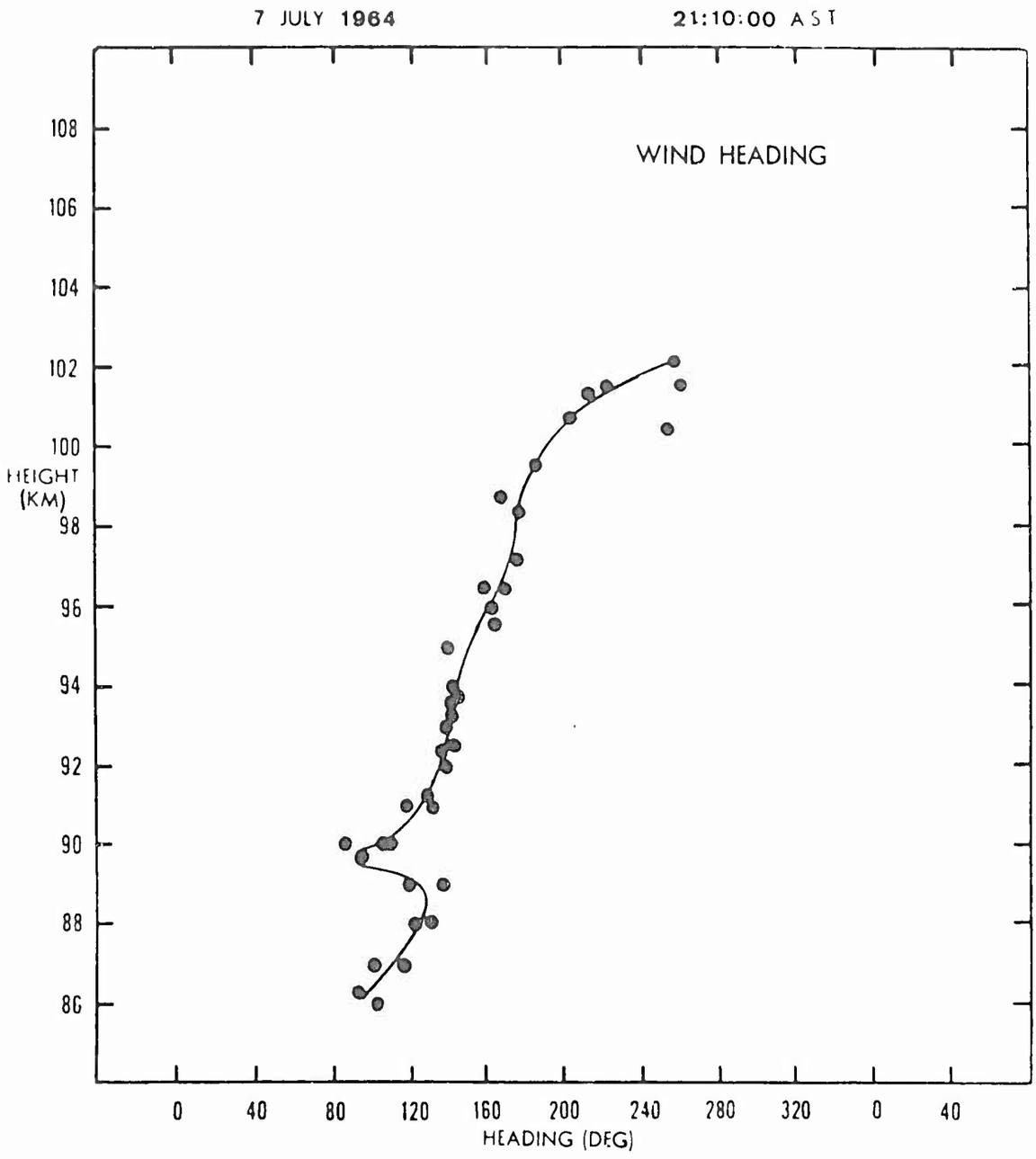
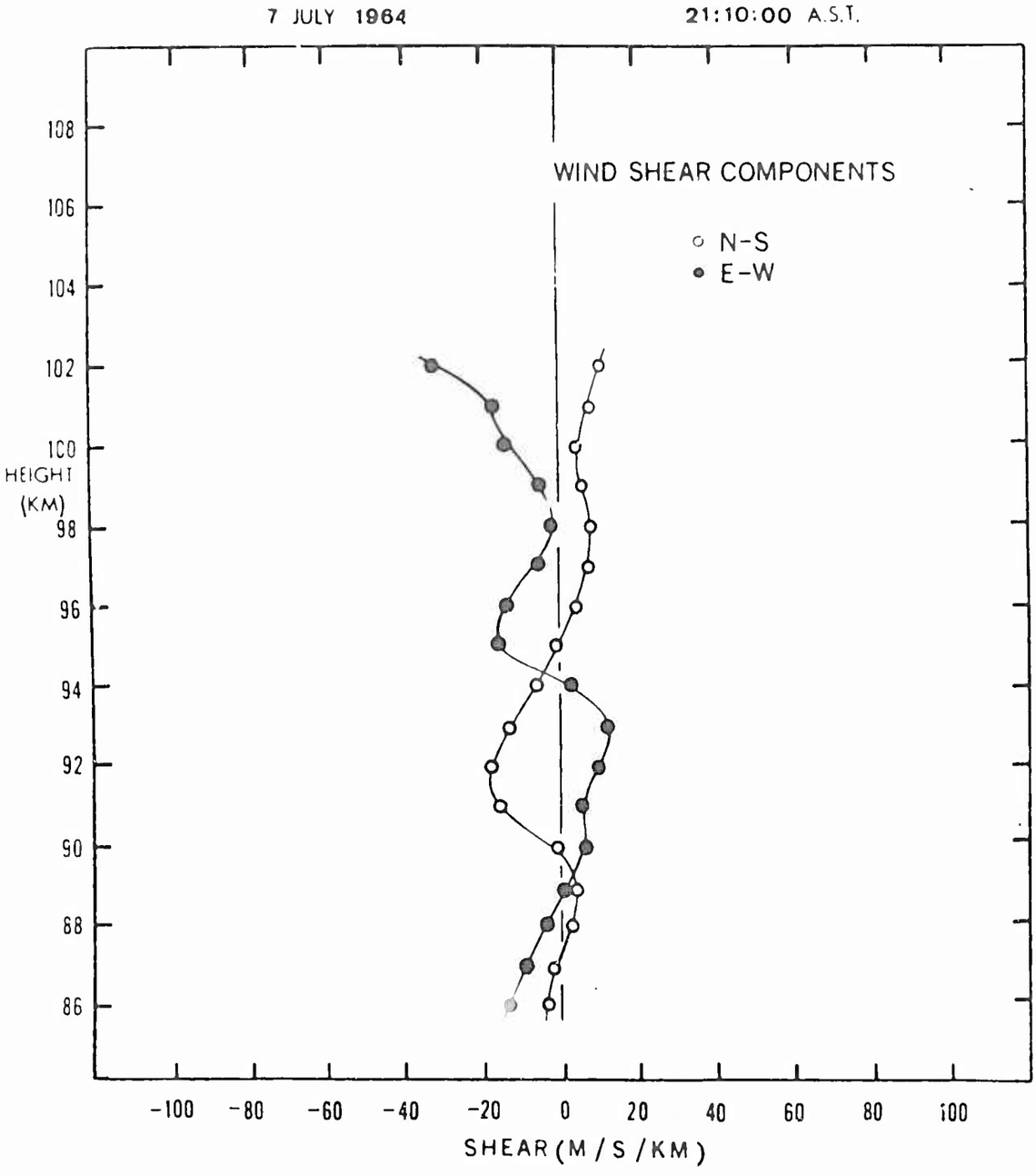
21:10:00 A.S.T.
WIND VELOCITY
HEIGHT (KM)
108
106
104
102
100
98
96
94
92
90
88
86
20
40
60
80
100
120
VELOCITY (M/S)

JANET


7 JULY 1964
21:10:00 AST
WIND HEADING
HEIGHT (KM)
108
106
104
102
100
98
96
94
92
90
88
86
0
40
80
120
160
200
240
280
320
0
40
HEADING (DEG)

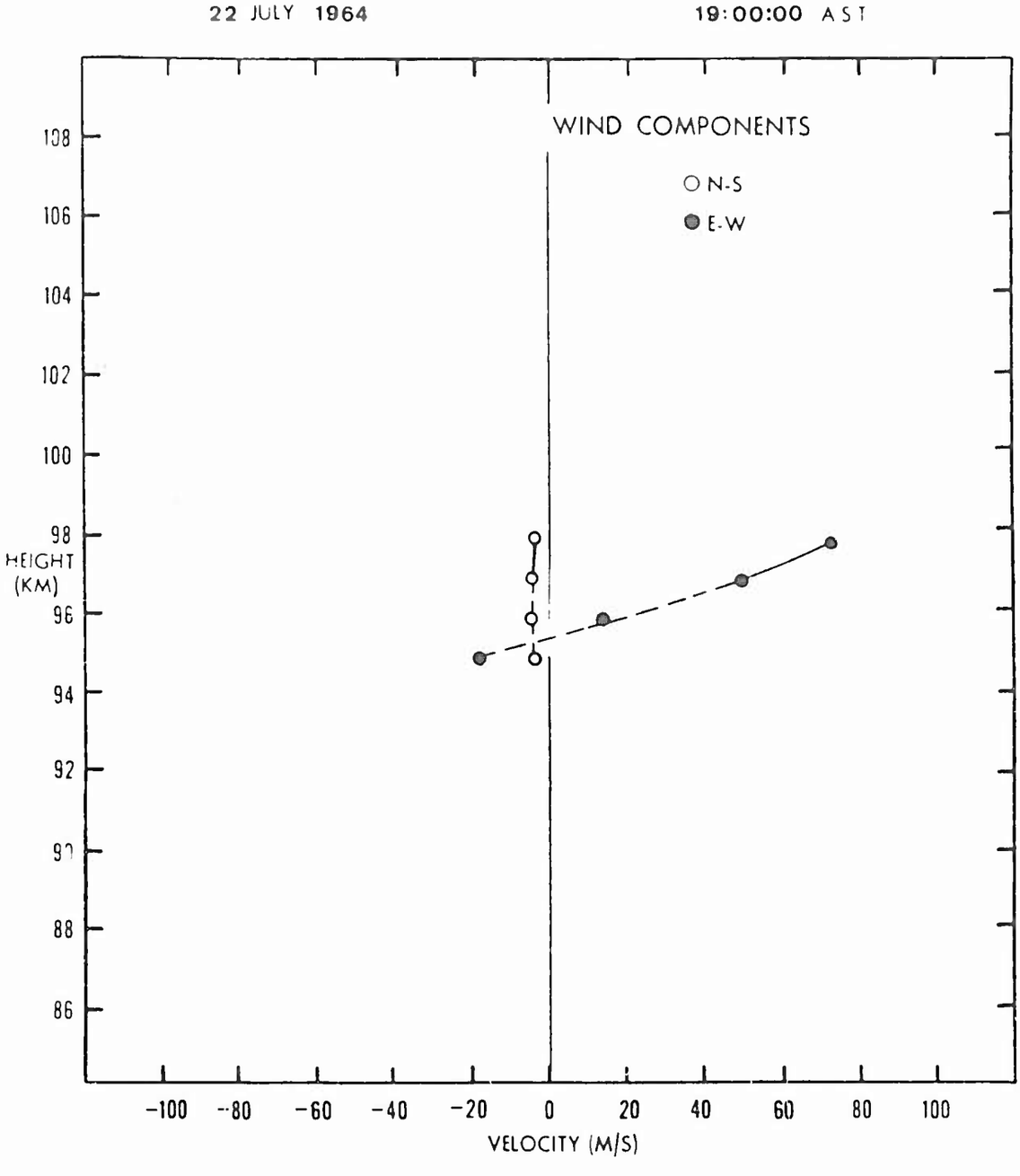
JANET


7 JULY 1964
21:10:00 A.S.T.
WIND SHEAR COMPONENTS
N-S
E-W
HEIGHT (KM)
108
106
104
102
100
98
96
94
92
90
88
86
-100
-80
-60
-40
-20
0
20
40
60
80
100
SHEAR (M/S/KM)

SHOT SHARON 22 JULY 1964 19-00-00 AST

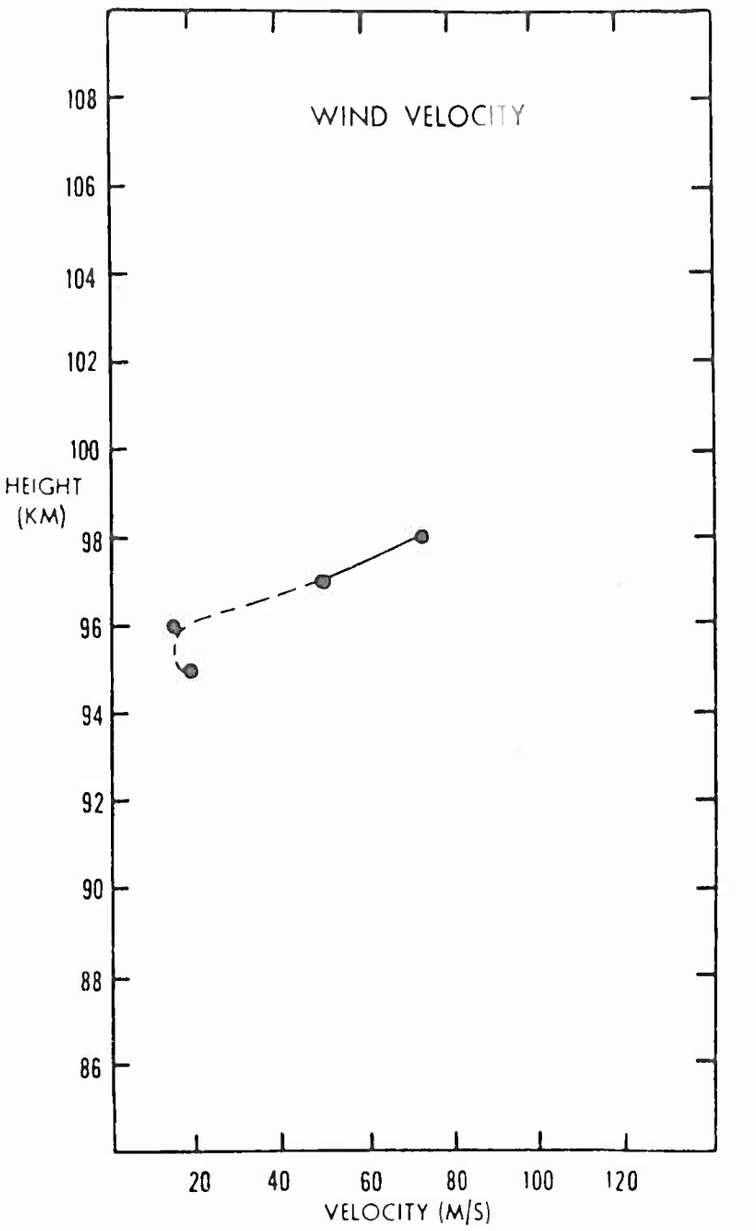
ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
95.0	257.7	18.9	-4.0	-18.5
96.0	112.3	14.8	-5.6	13.7
97.0	95.9	49.3	-5.1	49.0
98.0	93.6	72.1	-4.6	71.9

SHARON

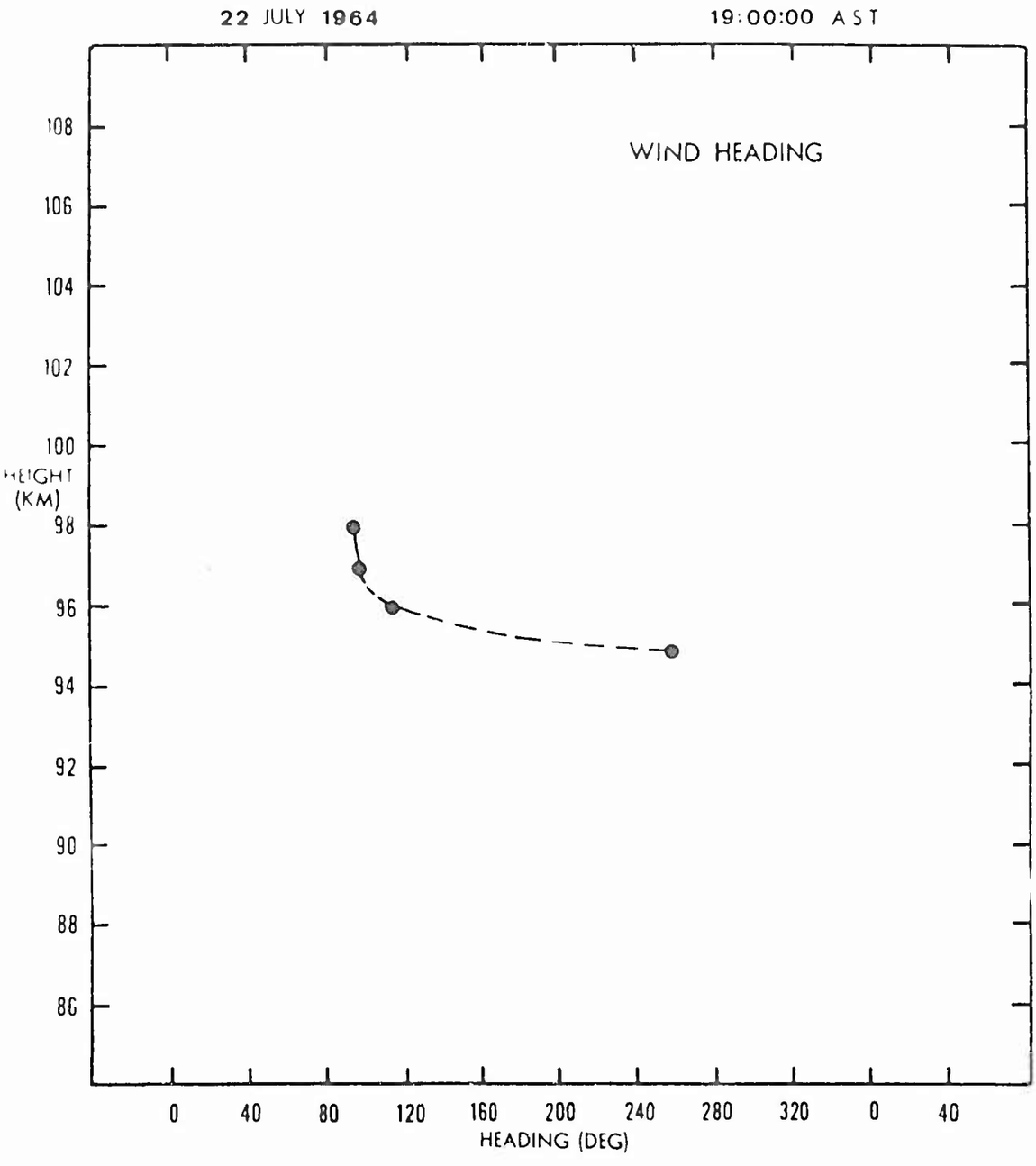

22 JULY 1964
19:00:00 AST
WIND COMPONENTS
N-S
E-W
108
106
104
102
100
98
96
94
92
90
88
86
HEIGHT (KM)
-100
-80
-60
-40
-20
0
20
40
60
80
100
VELOCITY (M/S)

SHARON

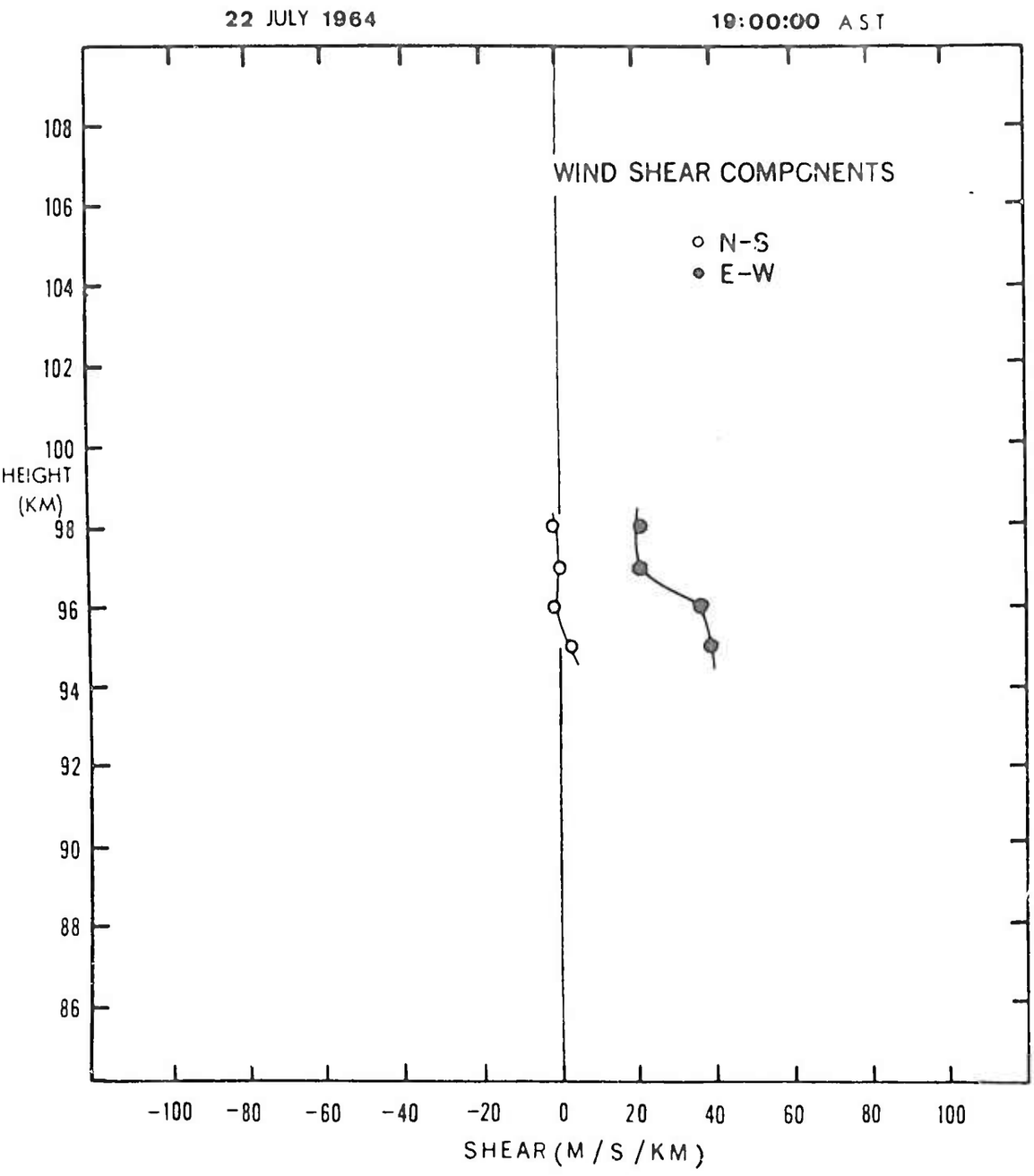
22 JULY 1964 19:00:00 AST



SHARON


22 JULY 1964
19:00:00 AST
WIND HEADING
108
106
104
102
100
98
96
94
92
90
88
86
HEIGHT (KM)
0
40
80
120
160
200
240
280
320
0
40
HEADING (DEG)

SHARON

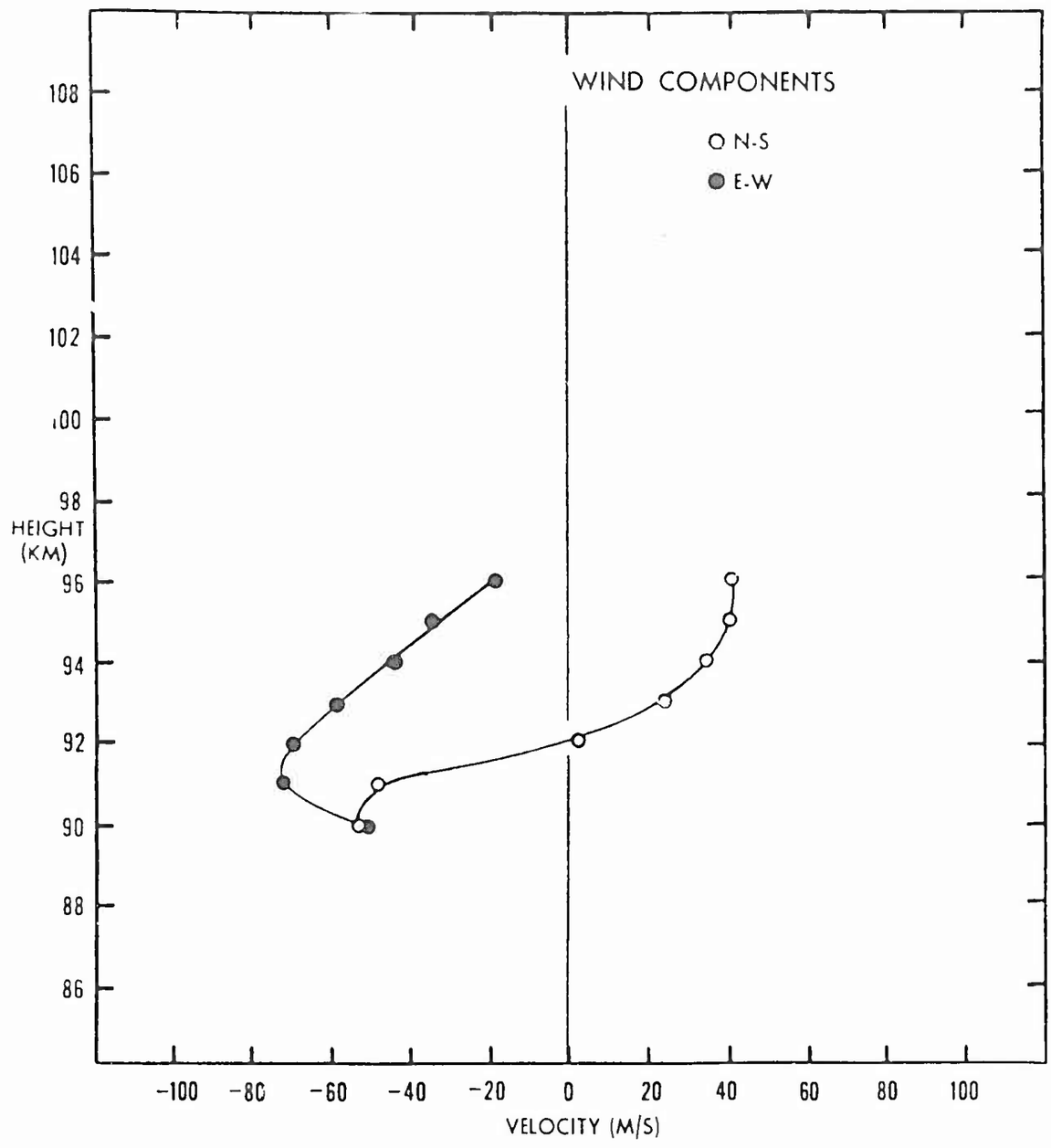

22 JULY 1964
19:00:00 AST
WIND SHEAR COMPONENTS
N-S
E-W
HEIGHT (KM)
108
106
104
102
100
98
96
94
92
90
88
86
-100
-80
-60
-40
-20
0
20
40
60
80
100
SHEAR (M/S/KM)

SHOT QUEENIE 24 JULY 1964 19-45-00 AST

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
90.0	223.7	73.8	-53.4	-51.0
91.0	236.2	86.8	-48.3	-72.2
92.0	272.7	69.3	3.3	-69.2
93.0	292.8	62.9	24.4	-58.0
94.0	308.6	55.7	34.7	-43.5
95.0	319.8	53.0	40.5	-34.2
96.0	336.1	44.5	40.6	-18.0

QUEENIE

24 JULY 1964 19:45:00 A S T.



QUEENIE

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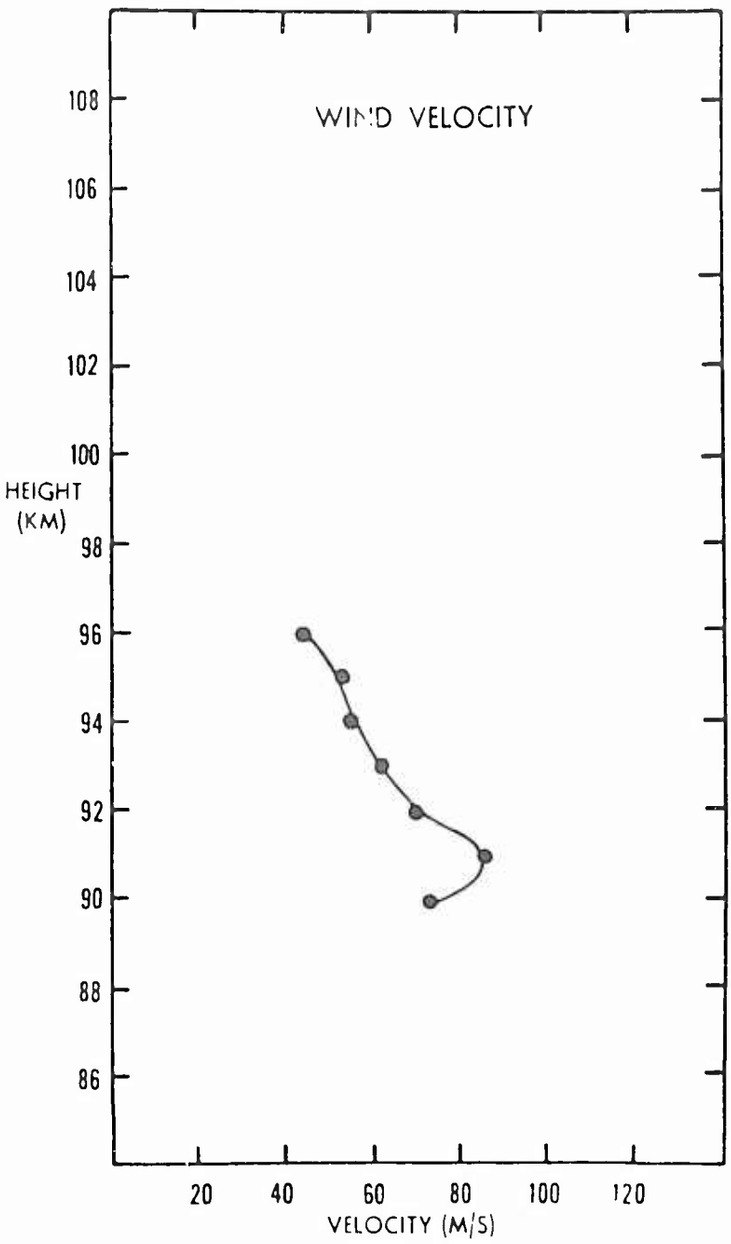

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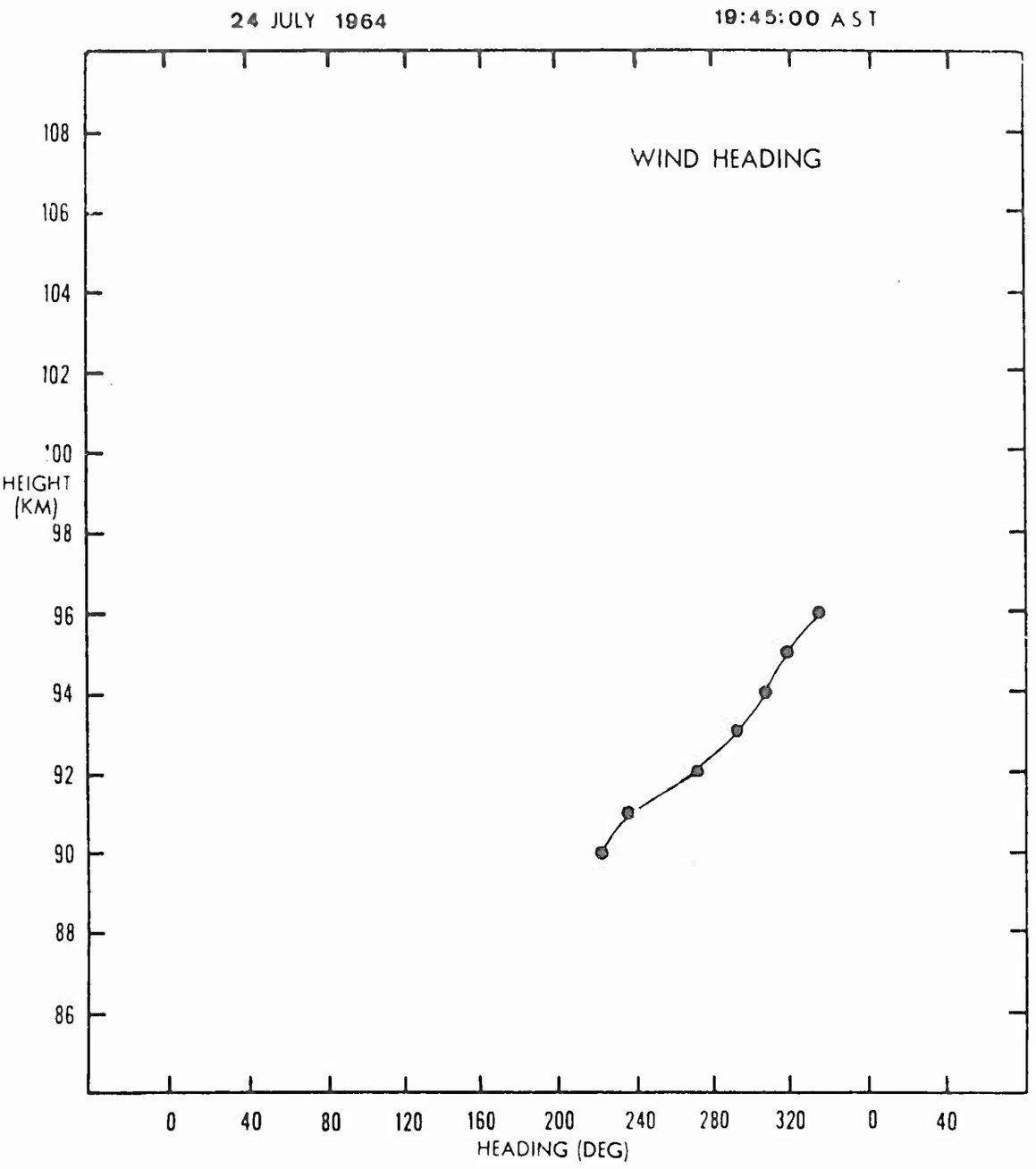
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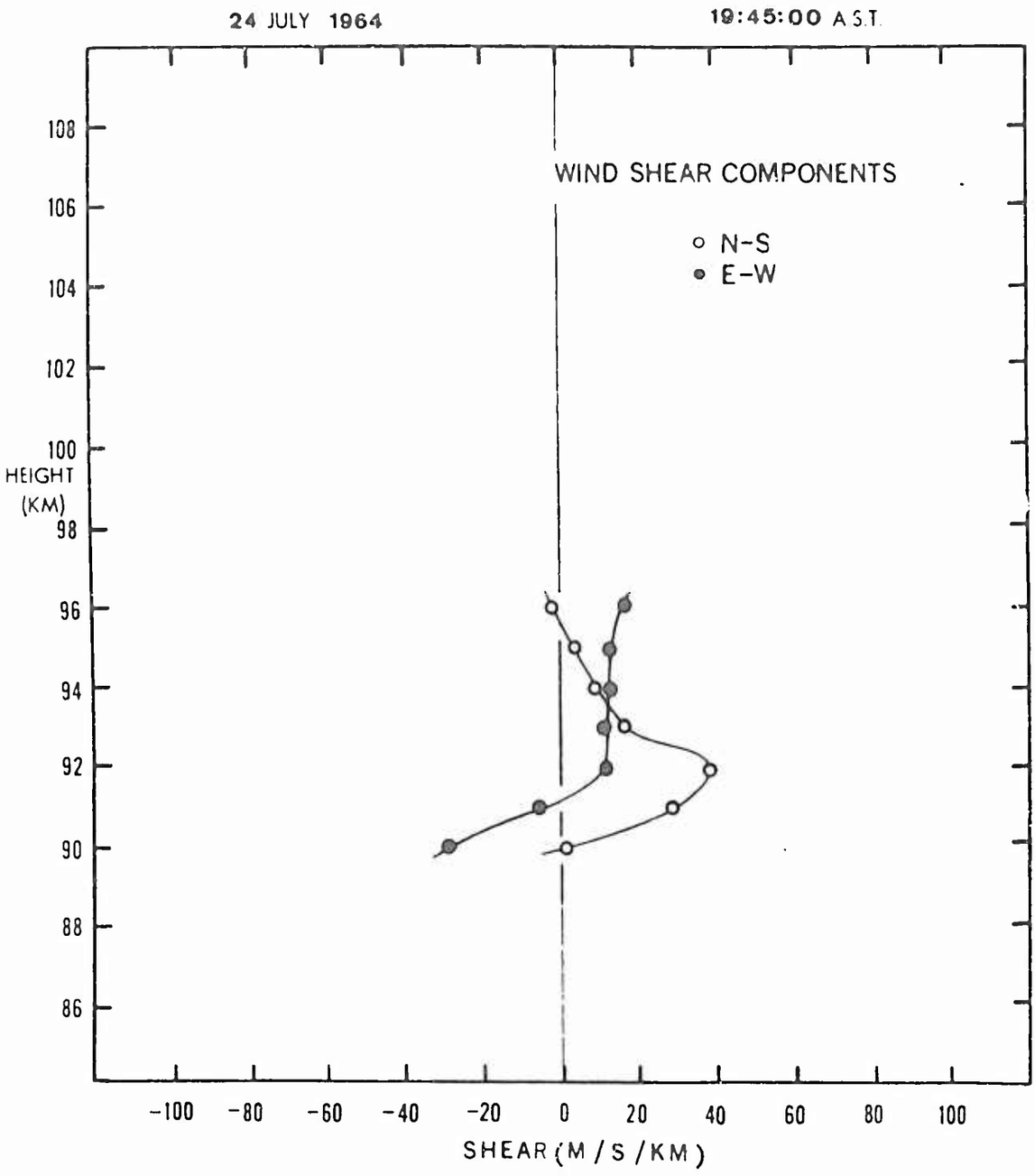
19:45:00 AST
WIND HEADING
108
106
104
102
100
HEIGHT (KM)
98
96
94
92
90
88
86
0
40
80
120
160
200
240
280
320
0
40
HEADING (DEG)

QUEENIE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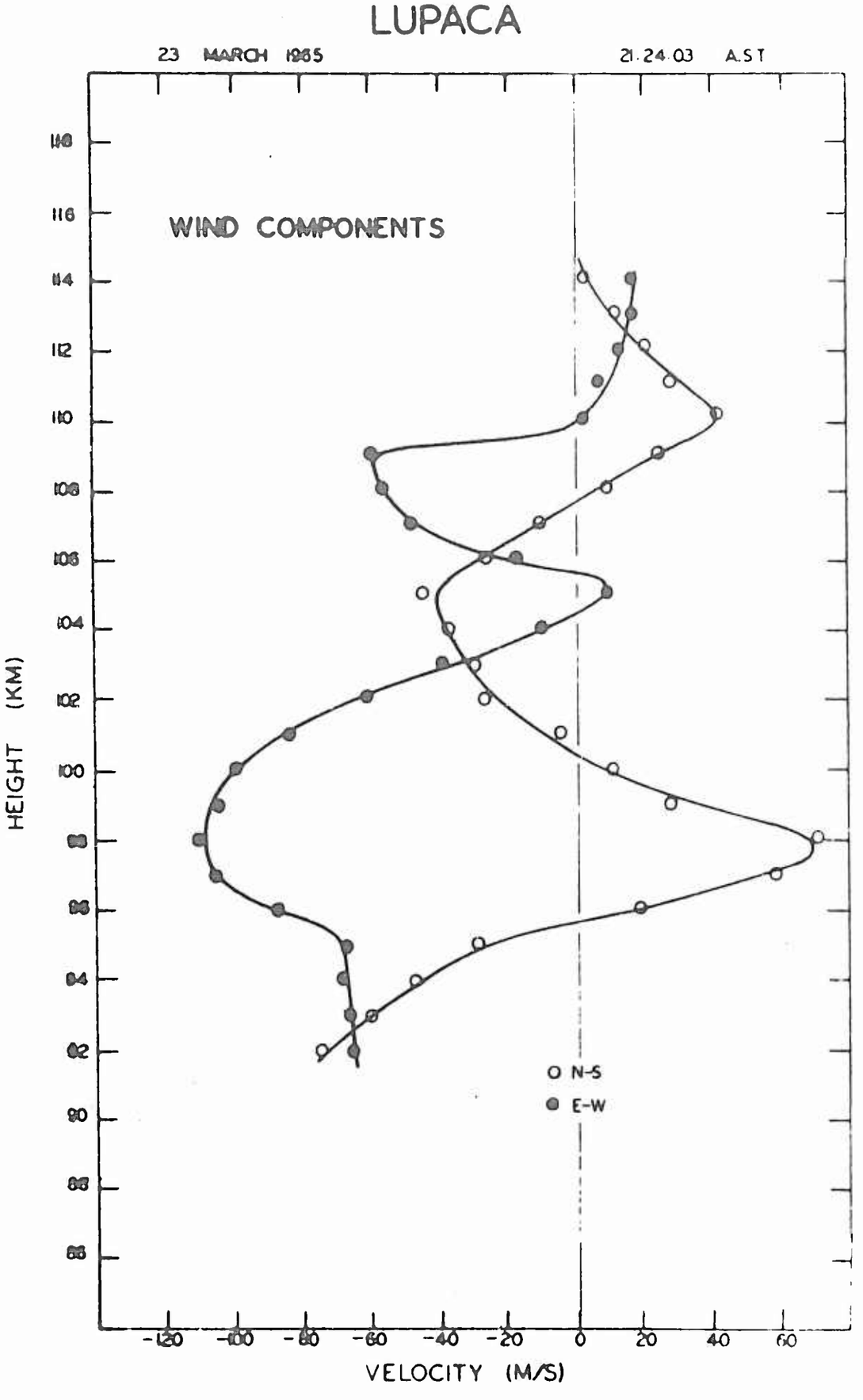
19:45:00 A.S.T.
WIND SHEAR COMPONENTS
N-S
E-W
HEIGHT (KM)
108
106
104
102
100
98
96
94
92
90
88
86
-100
-80
-60
-40
-20
0
20
40
60
80
100
SHEAR (M/S/KM)

SECTION II

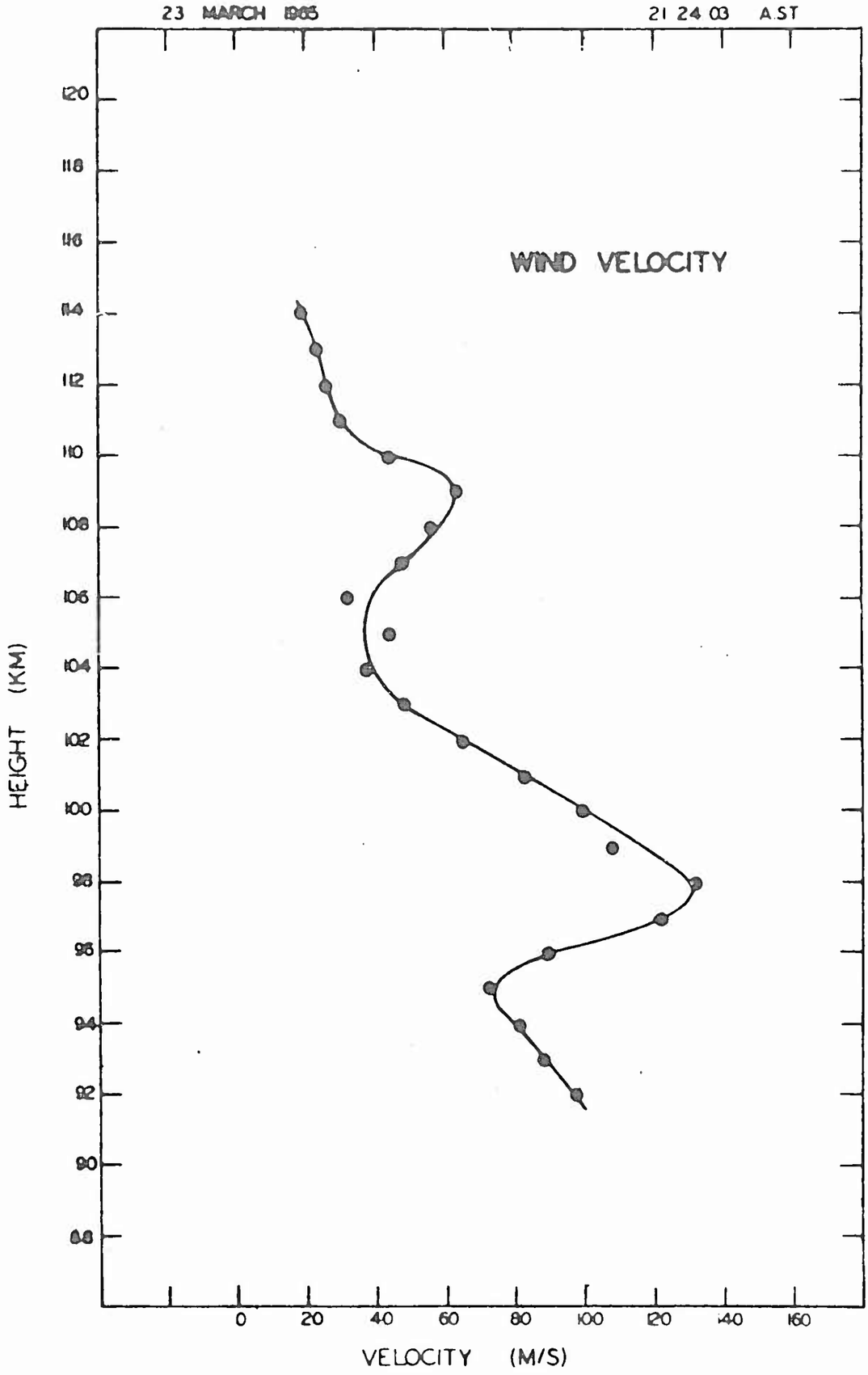
FIVE TRAIL RELEASES March 23-28, 1965

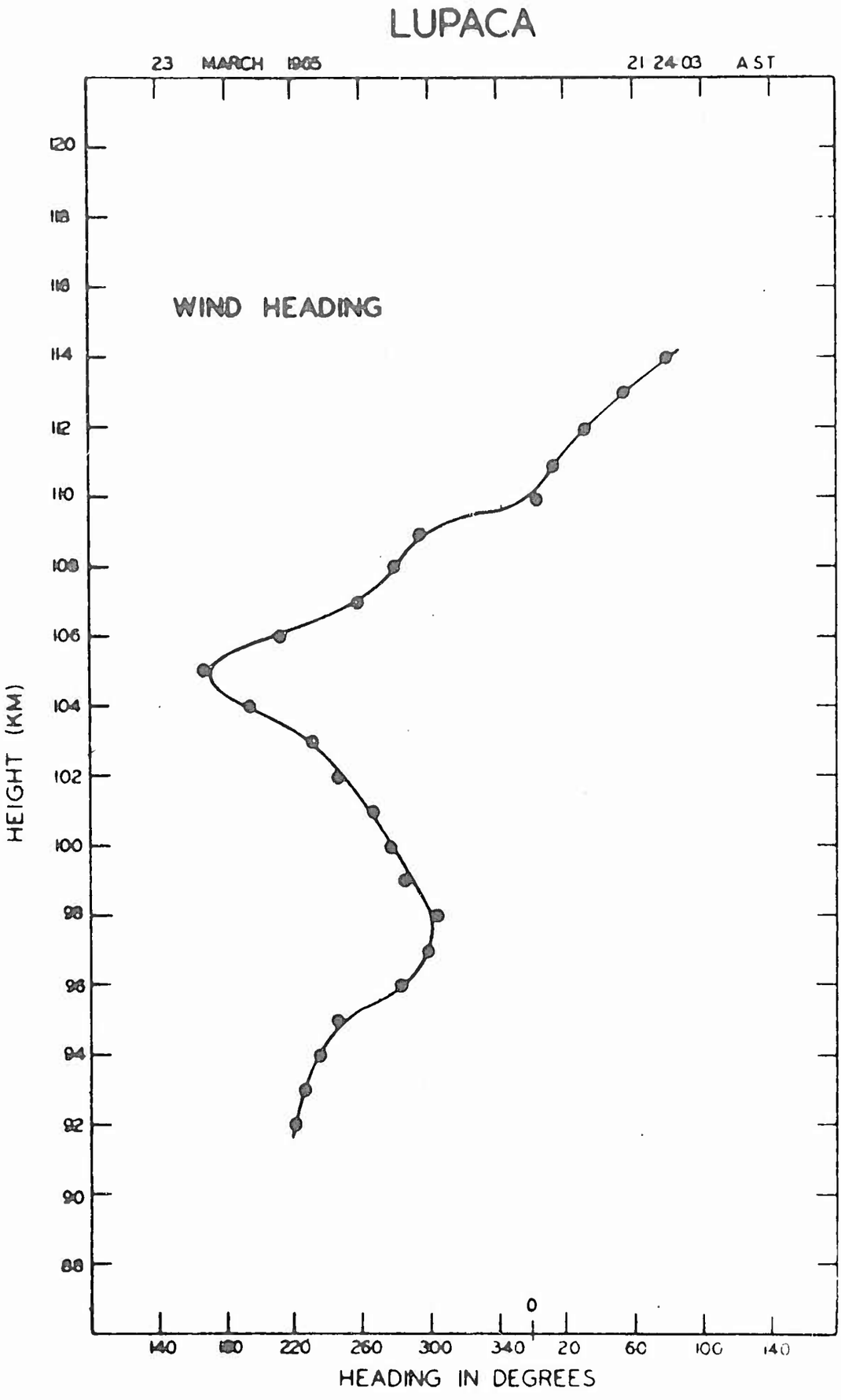
SHOT LUPAKA 23 MARCH 1965 21-24-03 AST

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
92.0	221.1	98.2	-74.0	64.9
93.0	227.8	88.0	-59.2	65.1
94.0	235.8	81.2	-45.7	67.2
95.0	247.3	71.7	-27.7	66.2
96.0	283.1	89.3	20.2	-87.0
97.0	299.4	121.0	59.3	-105.5
98.0	302.6	130.8	70.5	-110.2
99.0	285.3	107.7	28.5	-103.8
100.0	276.6	99.3	11.5	-98.7
101.0	267.1	82.9	-4.2	-82.8
102.0	246.8	65.3	-25.7	-60.0
103.0	232.5	47.7	-29.0	-37.8
104.0	194.7	37.4	36.2	-9.5
105.0	166.8	44.7	-43.5	10.2
106.0	214.0	31.0	-25.7	-17.3
107.0	258.2	47.9	-9.8	-46.9
108.0	280.4	55.9	10.1	-55.0
109.0	293.0	63.0	24.6	-58.0
110.0	3.8	42.9	42.8	2.8
111.0	14.3	30.4	29.5	7.5
112.0	32.4	25.8	21.8	13.8
113.0	54.0	22.7	13.3	18.3
114.0	79.2	18.7	3.5	18.3

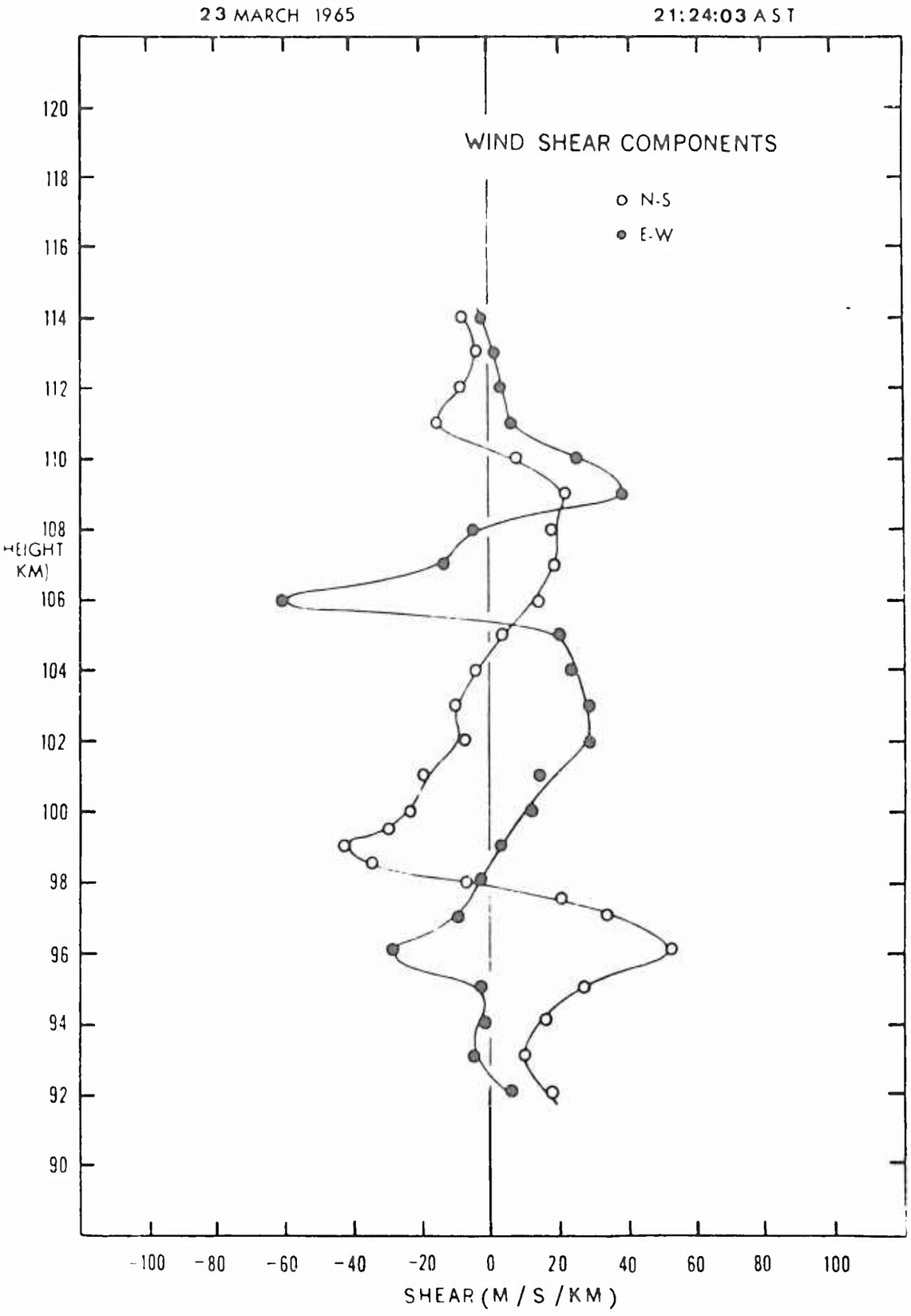

LUPACA
23 MARCH 1985
21.24.03 A.S.T
WIND COMPONENTS
HEIGHT (KM)
VELOCITY (M/S)
O N-S
● E-W

LUPACA


23 MARCH 1965
21 24 03 A.ST
WIND VELOCITY
HEIGHT (KM)
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
88
0
20
40
60
80
100
120
140
160
VELOCITY (M/S)


LUPACA
23 MARCH 1965
21 24 03 AST
WIND HEADING
HEIGHT (KM)
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
88
0
140
180
220
260
300
340
20
60
100
140
HEADING IN DEGREES

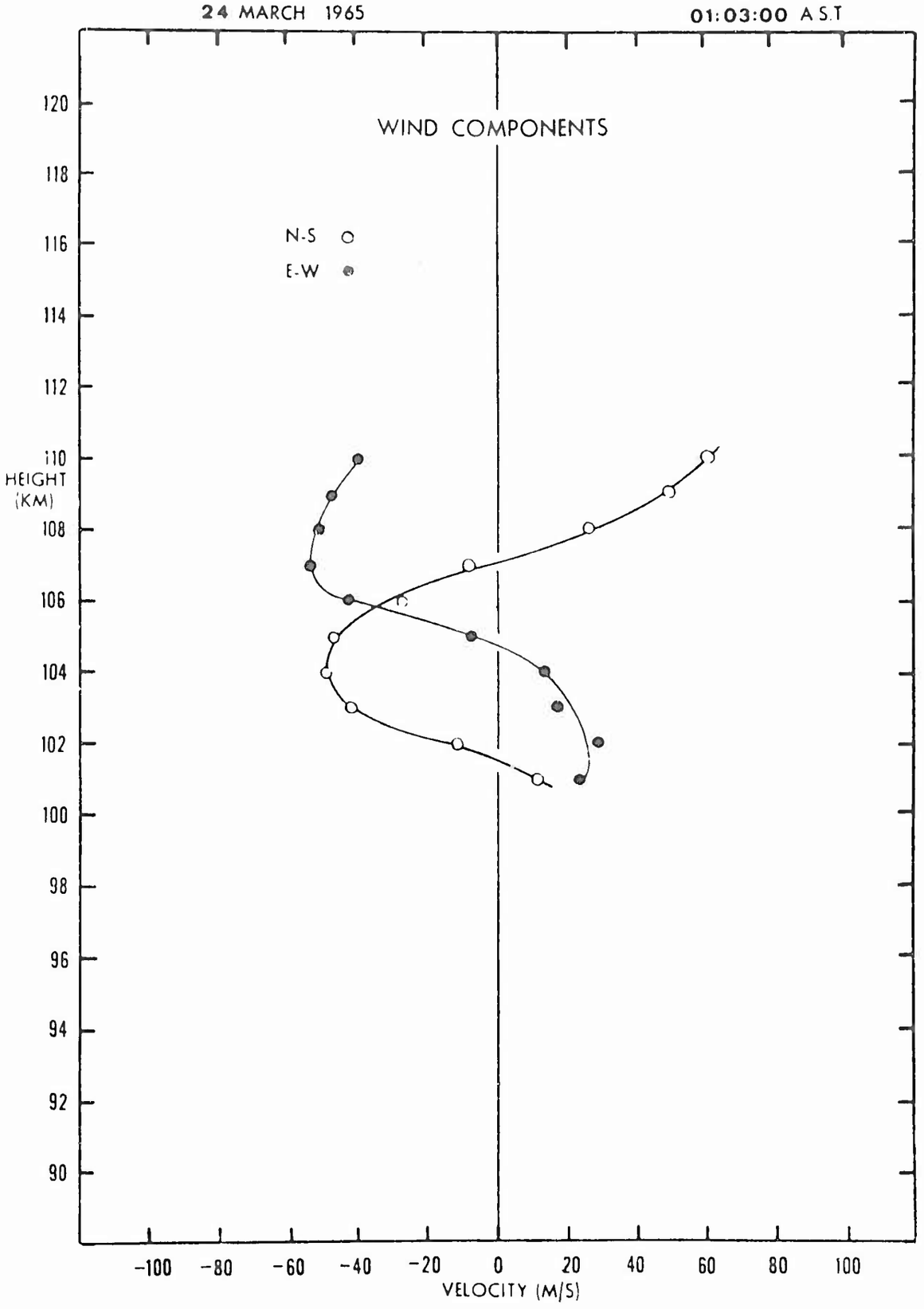
LUPAKA

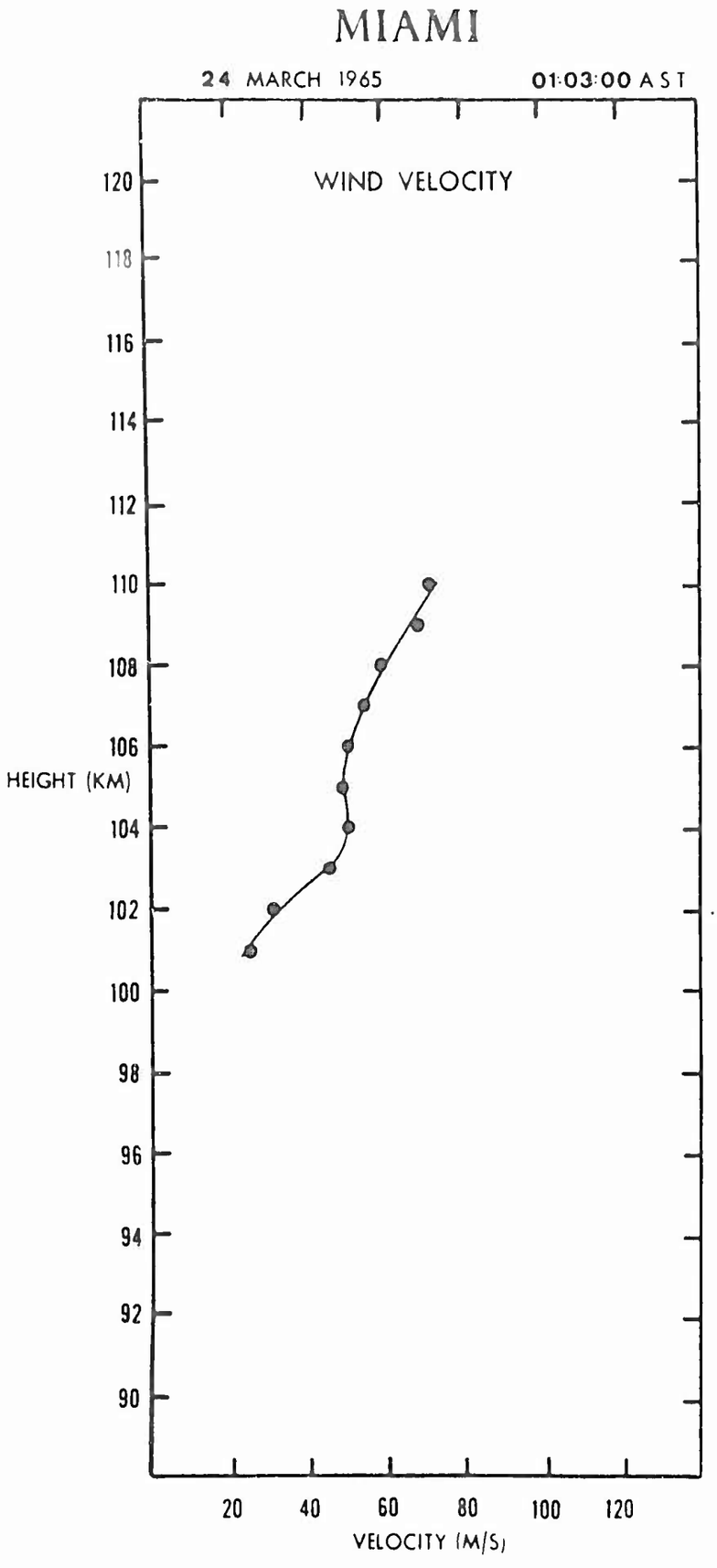

23 MARCH 1965
21:24:03 A S T
WIND SHEAR COMPONENTS
o N-S
• E-W
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
HEIGHT (KM)
-100
-80
-60
-40
-20
0
20
40
60
80
100
SHEAR (M / S / KM)

SHOT MIAMI 24 MARCH 1965 01-0[illegible]-00 AST

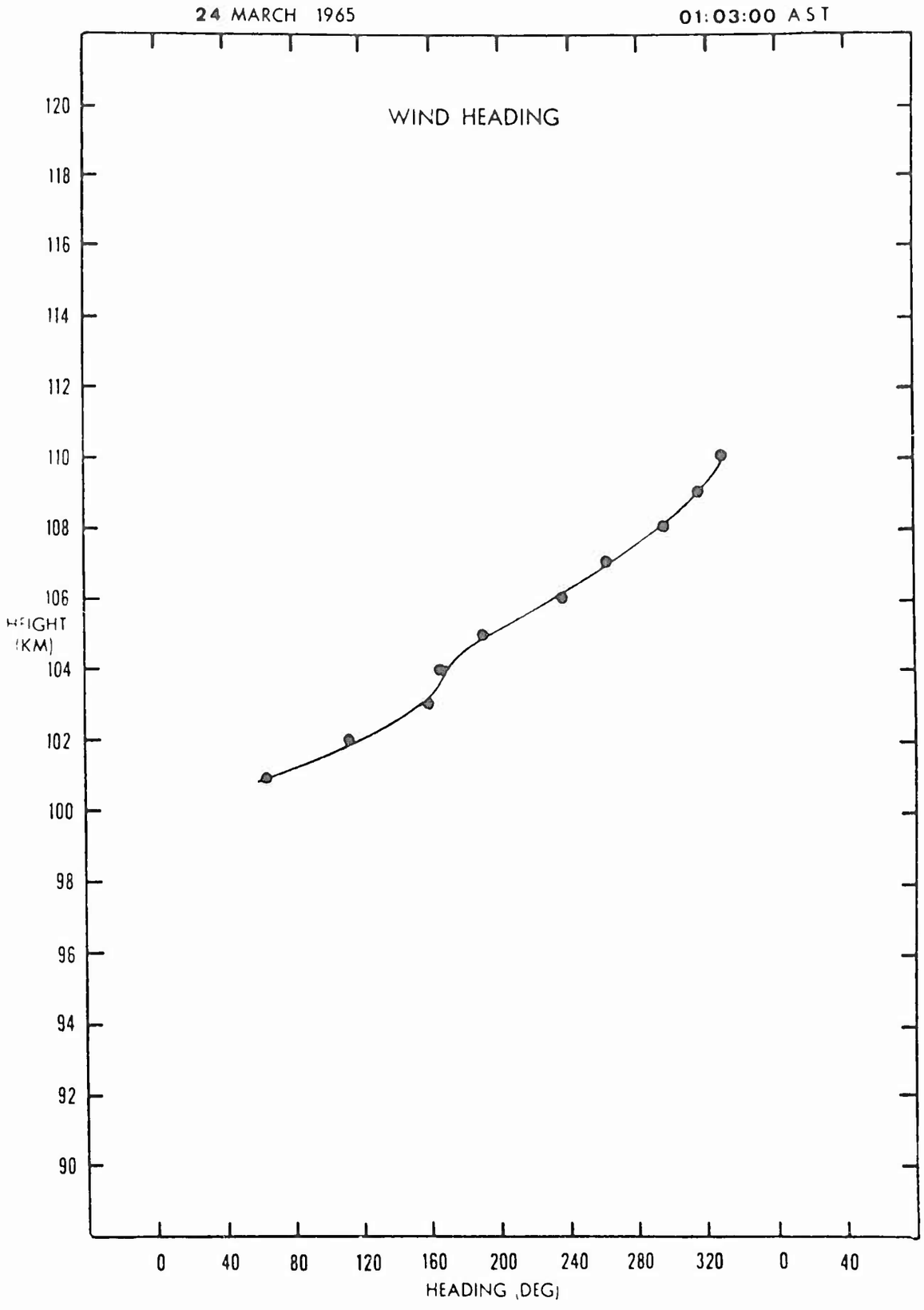
ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
101.0	64.2	25.2	11.0	22.7
102.0	112.1	31.1	-11.7	28.8
103.0	159.0	45.5	-42.5	16.3
104.0	165.0	50.4	-48.7	13.0
105.0	189.4	48.1	-47.4	-7.9
106.0	237.3	50.0	-27.0	-42.1
107.0	261.6	54.2	-7.9	-53.7
108.0	296.9	58.1	26.3	-51.8
109.0	317.0	68.4	50.1	-46.6
110.0	328.3	72.4	61.6	-38.1

MIAMI

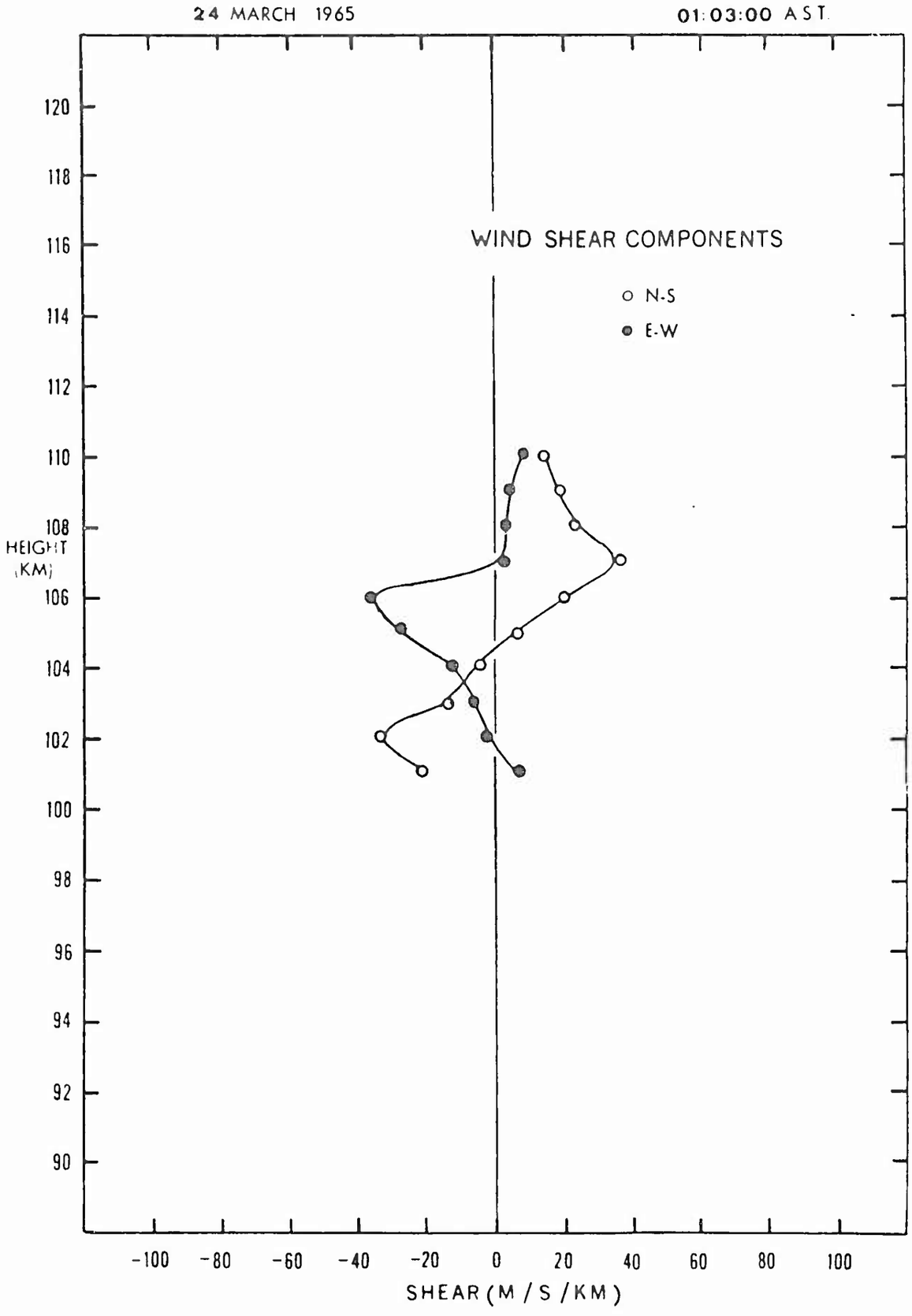

24 MARCH 1965
01:03:00 A.S.T
WIND COMPONENTS
N-S
E-W
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
HEIGHT (KM)
-100
-80
-60
-40
-20
0
20
40
60
80
100
VELOCITY (M/S)


MIAMI
24 MARCH 1965
01:03:00 A S T
WIND VELOCITY
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
HEIGHT (KM)
20
40
60
80
100
120
VELOCITY (M/S)

MIAMI


24 MARCH 1965
01:03:00 AST
WIND HEADING
120
118
116
114
112
110
108
106
HEIGHT
(KM)
104
102
100
98
96
94
92
90
0
40
80
120
160
200
240
280
320
0
40
HEADING (DEG)

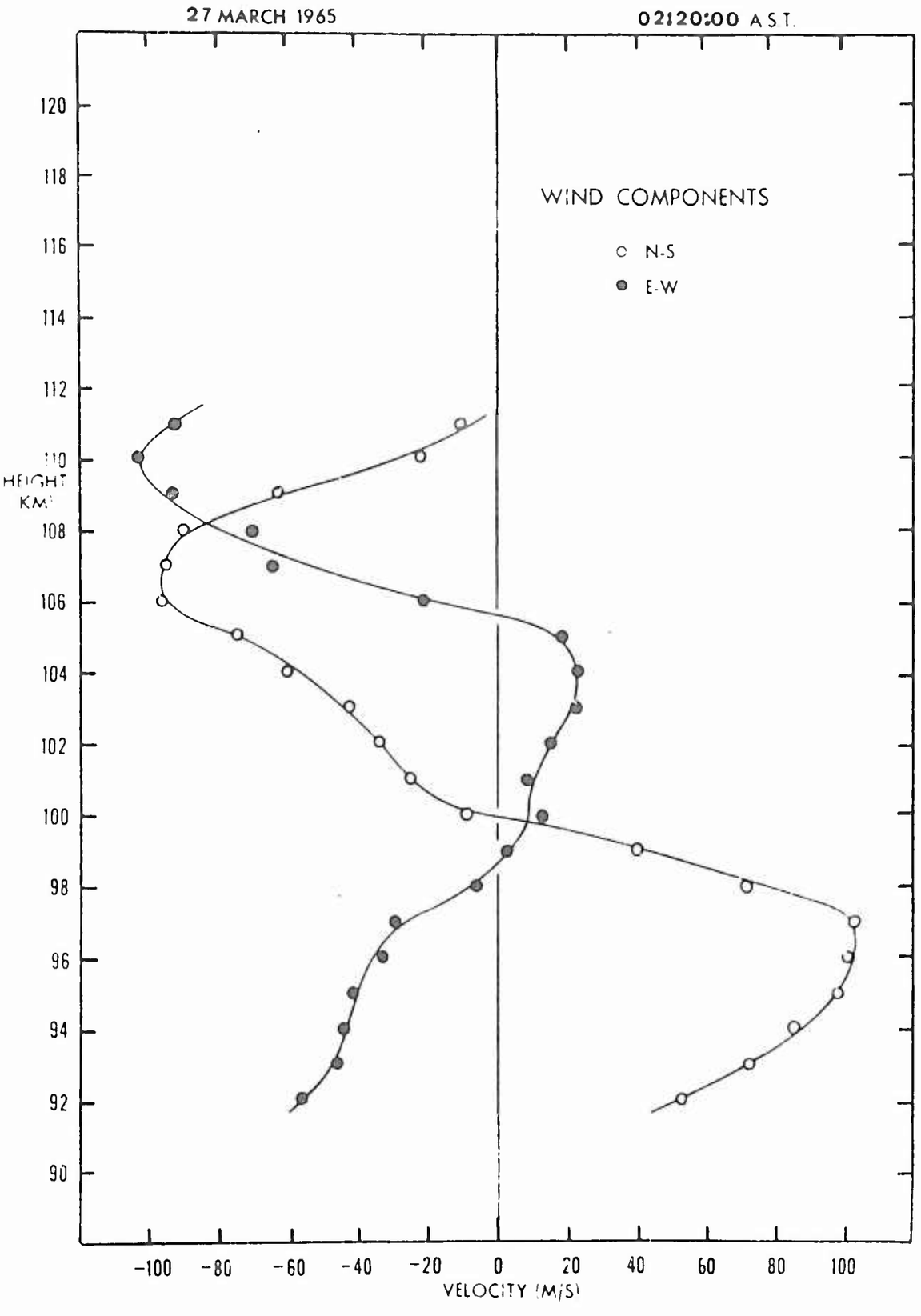
MIAMI


24 MARCH 1965
01:03:00 A.S.T.
WIND SHEAR COMPONENTS
N-S
E-W
HEIGHT (KM)
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
-100
-80
-60
-40
-20
0
20
40
60
80
100
SHEAR (M / S / KM)

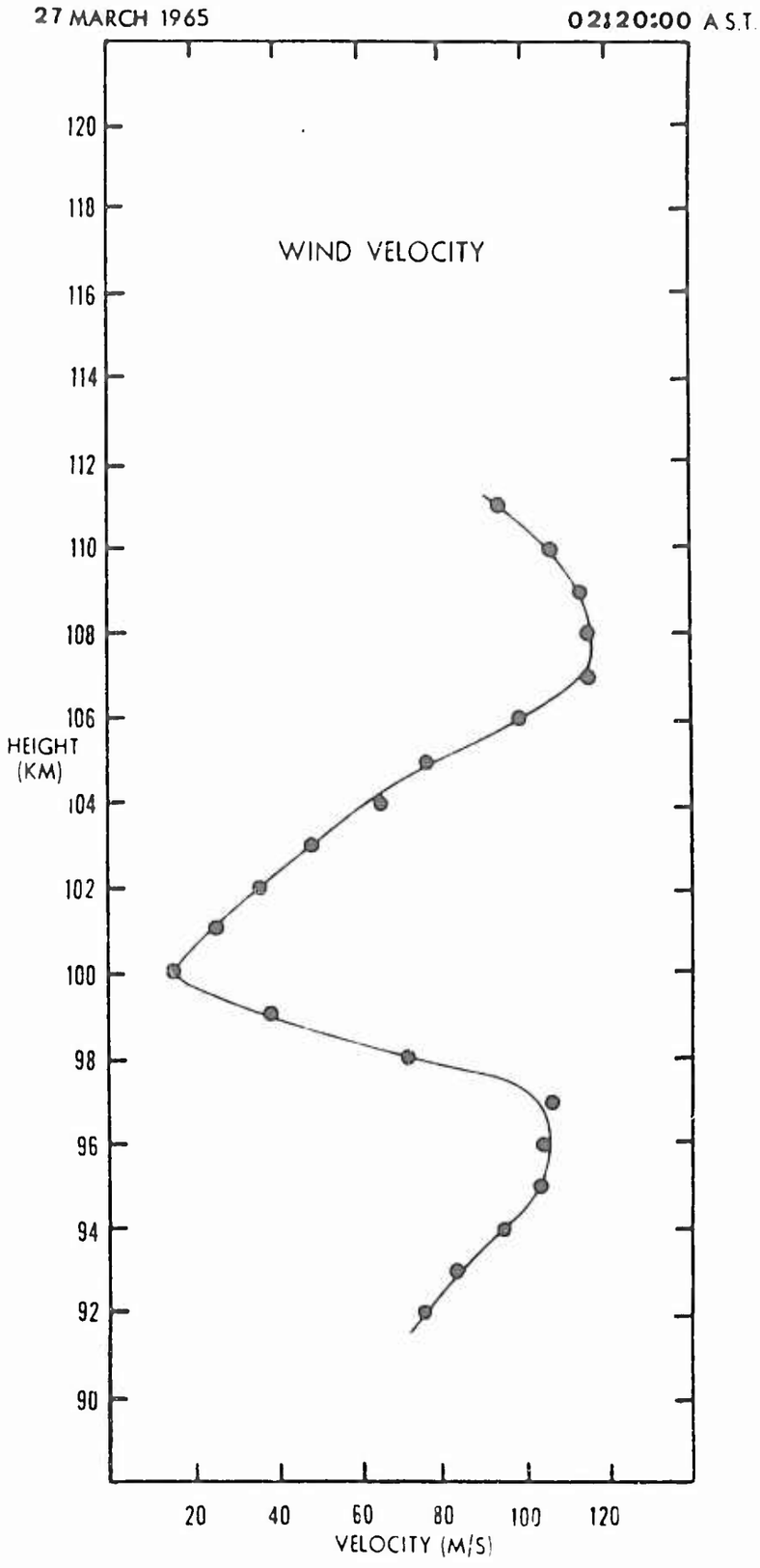
SHOT NOOTKA 27 MARCH 1965 02-20-00 AST

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
92.0	312.4	77.4	52.2	-57.2
93.0	327.4	85.8	72.3	-46.3
94.0	331.8	96.1	84.7	-45.3
95.0	336.6	105.6	96.8	-42.0
96.0	341.4	105.5	100.0	-33.6
97.0	343.6	106.7	102.4	-30.1
98.0	354.6	71.8	71.4	-6.7
99.0	2.9	39.0	39.0	2.0
100.0	130.6	15.6	-10.1	11.8
101.0	160.6	26.5	-25.0	8.8
102.0	157.1	36.9	-34.0	14.4
103.0	153.1	48.7	-43.4	22.1
104.0	159.9	65.0	-61.1	22.3
105.0	166.2	77.3	-75.0	18.5
106.0	192.7	99.1	-96.6	-21.8
107.0	214.5	115.6	-95.2	-65.5
108.0	218.1	115.4	-90.8	-71.3
109.0	235.7	113.1	-63.8	-93.4
110.0	258.0	105.4	-21.9	-103.1
111.0	262.9	93.5	-11.6	-92.8

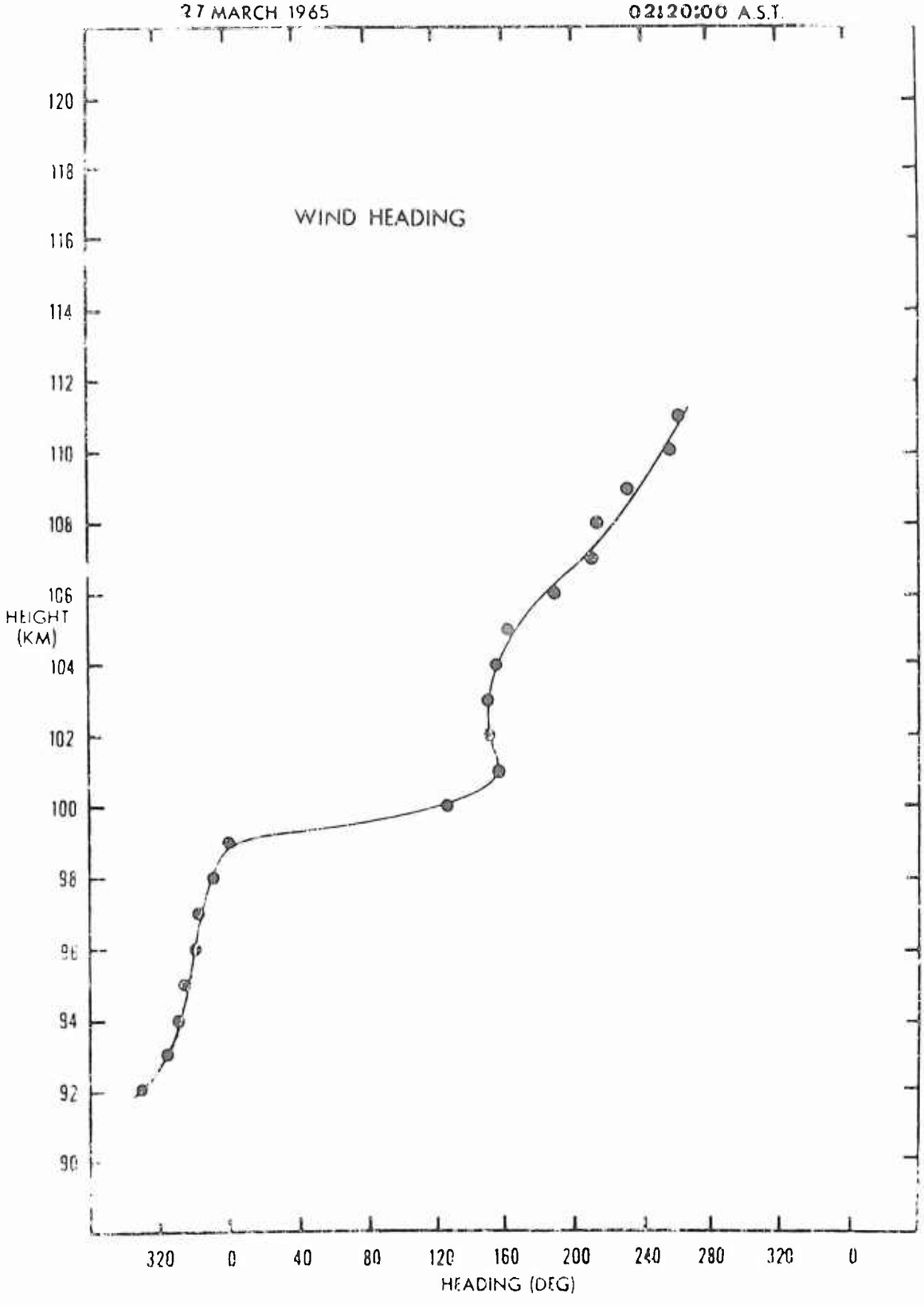
NOOTKA


27 MARCH 1965
02:20:00 A.S.T.
WIND COMPONENTS
N-S
E-W
HEIGHT KM
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
-100
-80
-60
-40
-20
0
20
40
60
80
100
VELOCITY (M/S)

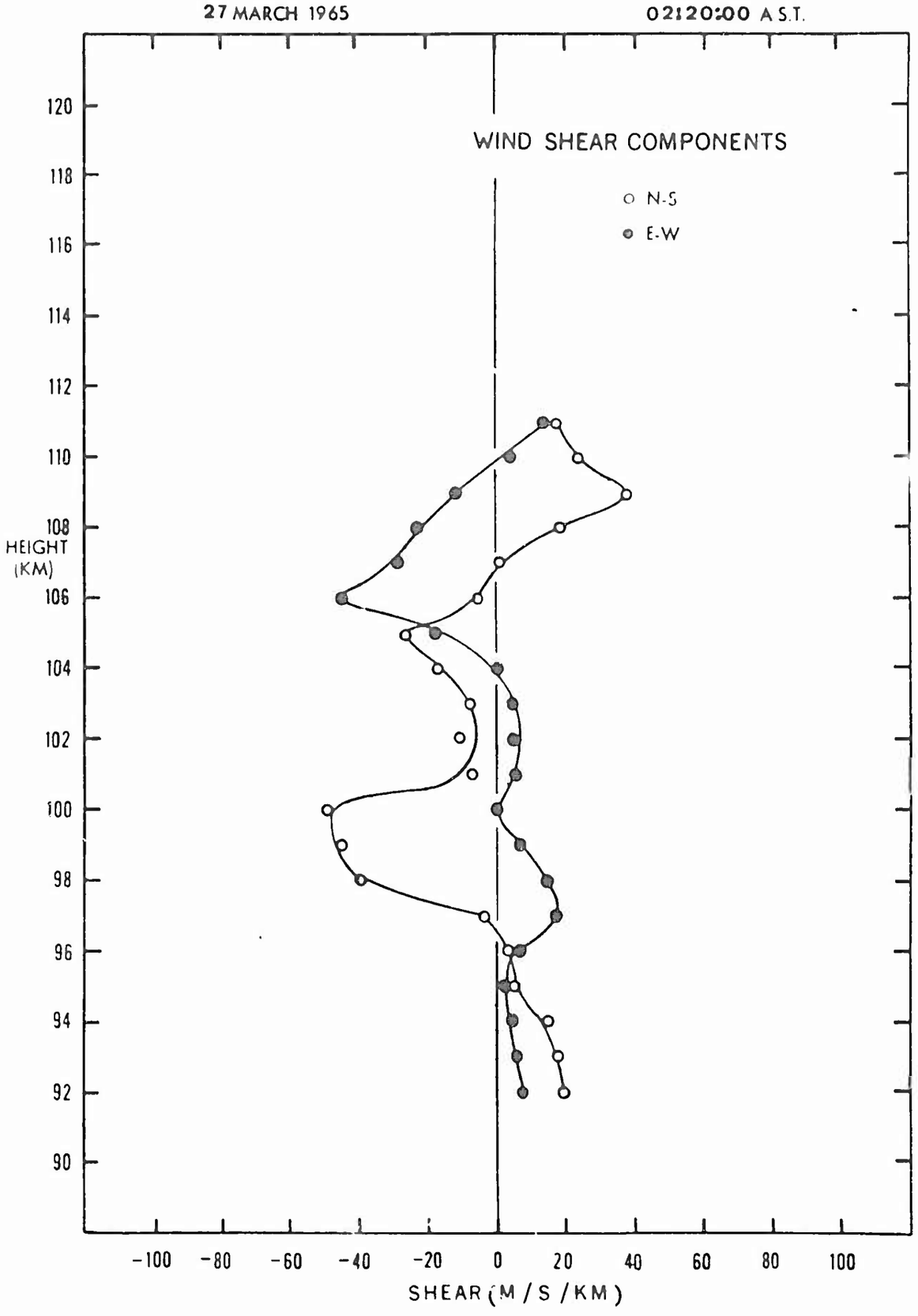
NOOTKA


27 MARCH 1965
02:20:00 A.S.T.
WIND VELOCITY
HEIGHT (KM)
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
20
40
60
80
100
120
VELOCITY (M/S)

NOOTKA


27 MARCH 1965
02:20:00 A.S.T.
WIND HEADING
HEIGHT (KM)
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
320
0
40
80
120
160
200
240
280
320
0
HEADING (DEG)

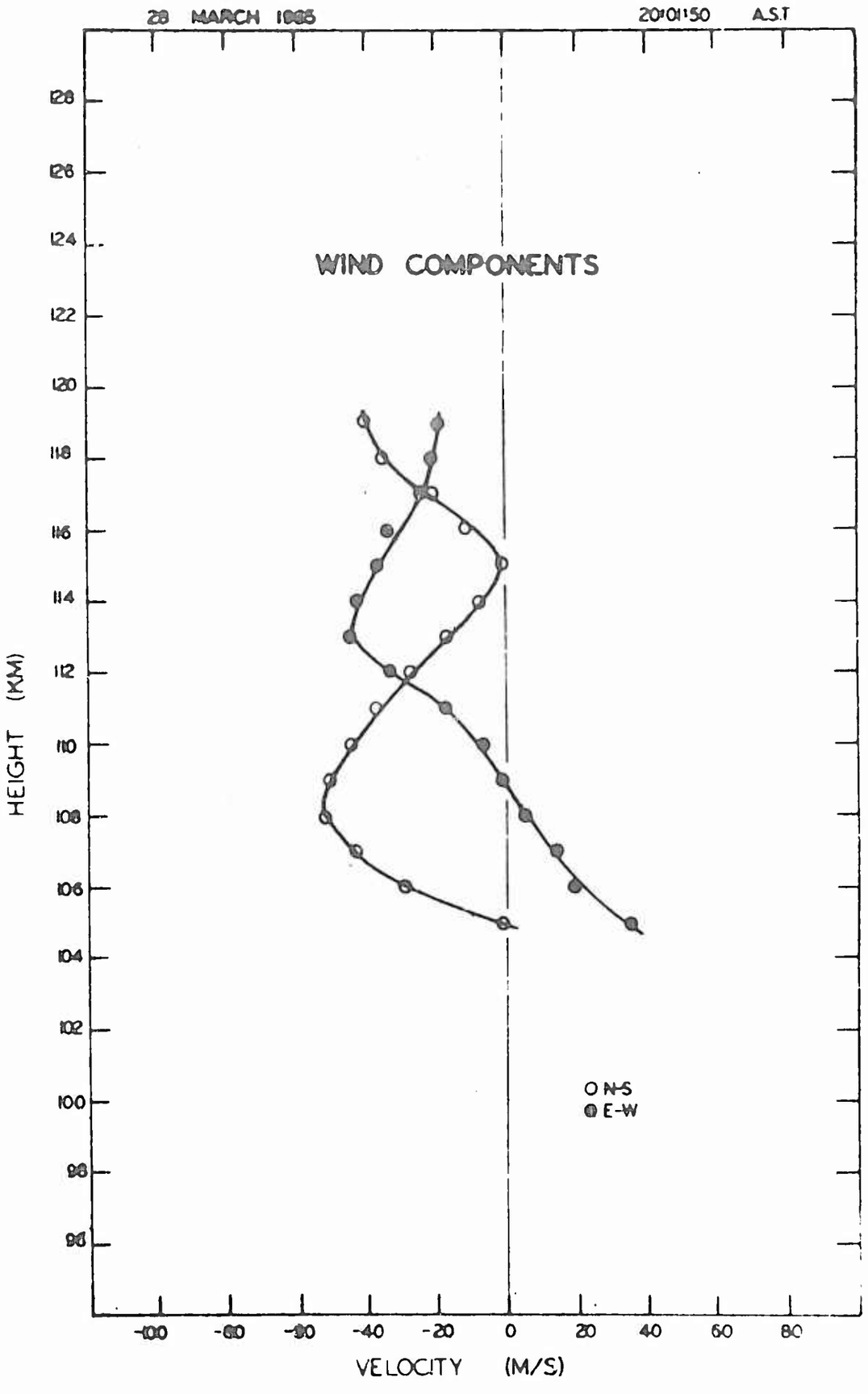
NOOTKA


27 MARCH 1965
02:20:00 A.S.T.
WIND SHEAR COMPONENTS
N-S
E-W
HEIGHT (KM)
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
-100
-80
-60
-40
-20
0
20
40
60
80
100
SHEAR (M / S / KM)

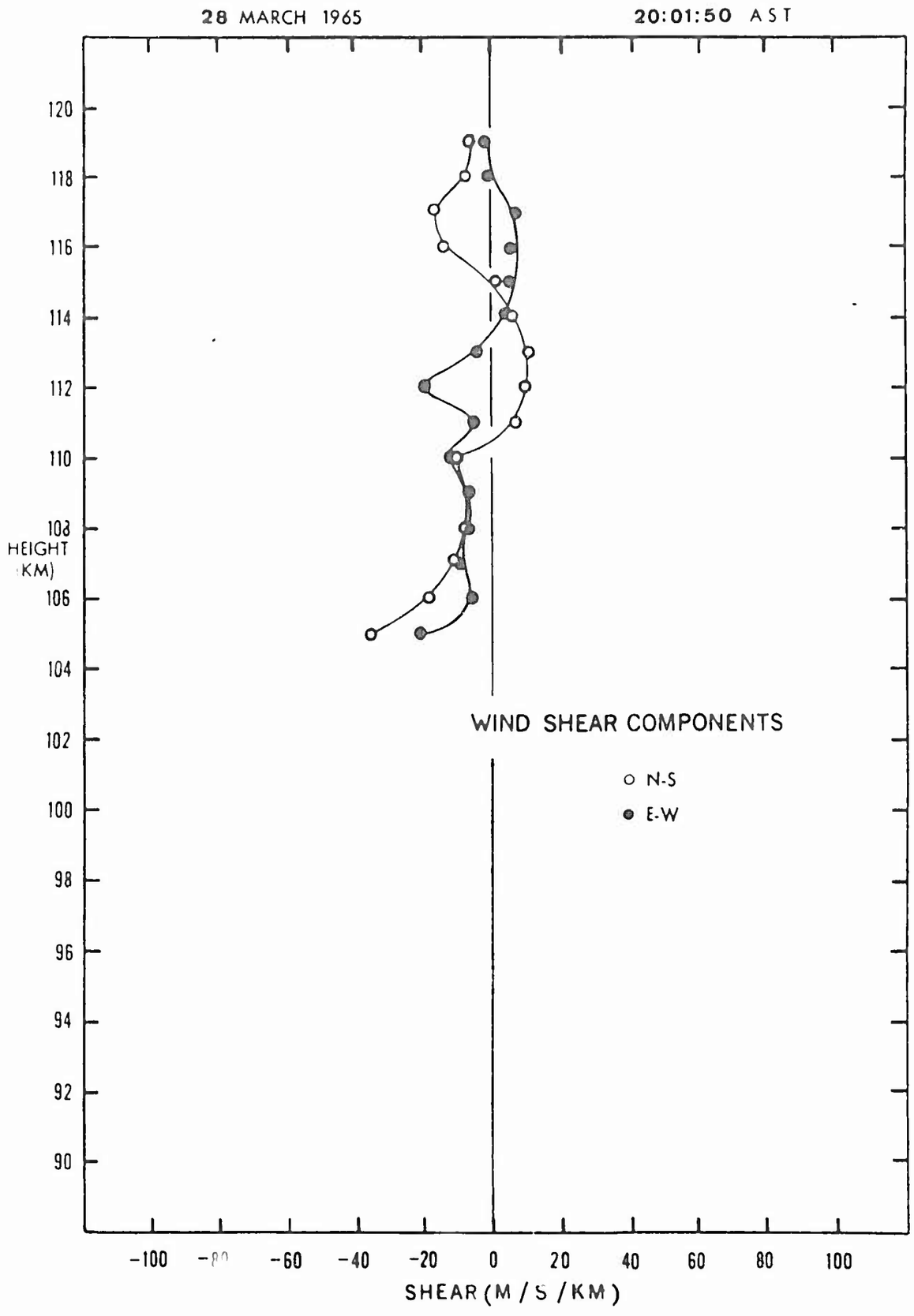
SHOT OTTAWA 28 MARCH 1965 20-01-50 AST

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
105.0	91.4	35.3	-0.9	35.3
106.0	146.6	35.2	-29.3	19.4
107.0	161.5	45.0	-42.7	14.3
108.0	174.4	52.6	-52.3	5.2
109.0	180.7	51.2	-51.2	-0.6
110.0	188.3	44.5	-44.0	-6.4
111.0	205.5	41.3	-37.3	-17.8
112.0	231.3	42.8	-26.8	-33.4
113.0	249.0	48.5	-17.4	-45.2
114.0	260.0	43.8	-7.6	-43.1
115.0	267.3	37.0	-1.7	-37.0
116.0	252.9	35.9	-10.6	-34.3
117.0	227.4	30.3	-20.5	-22.3
118.0	211.4	41.3	-35.2	-21.5
119.0	205.8	44.9	-40.4	-19.6

OTTAWA

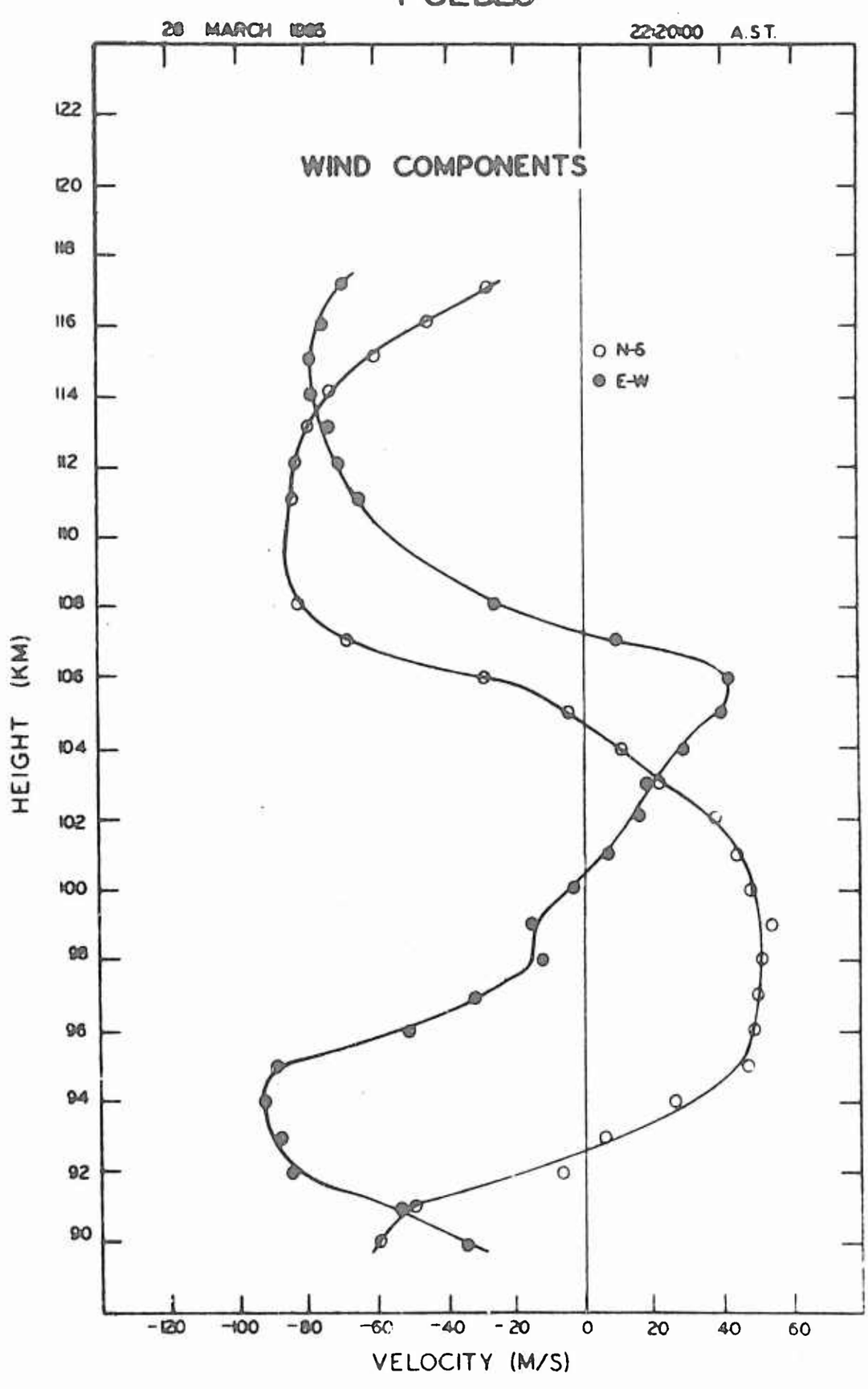

28 MARCH 1985
20:01:50 A.S.T
WIND COMPONENTS
HEIGHT (KM)
128
126
124
122
120
118
116
114
112
110
108
106
104
102
100
98
96
-100
-80
-60
-40
-20
0
20
40
60
80
VELOCITY (M/S)
O N-S
E-W

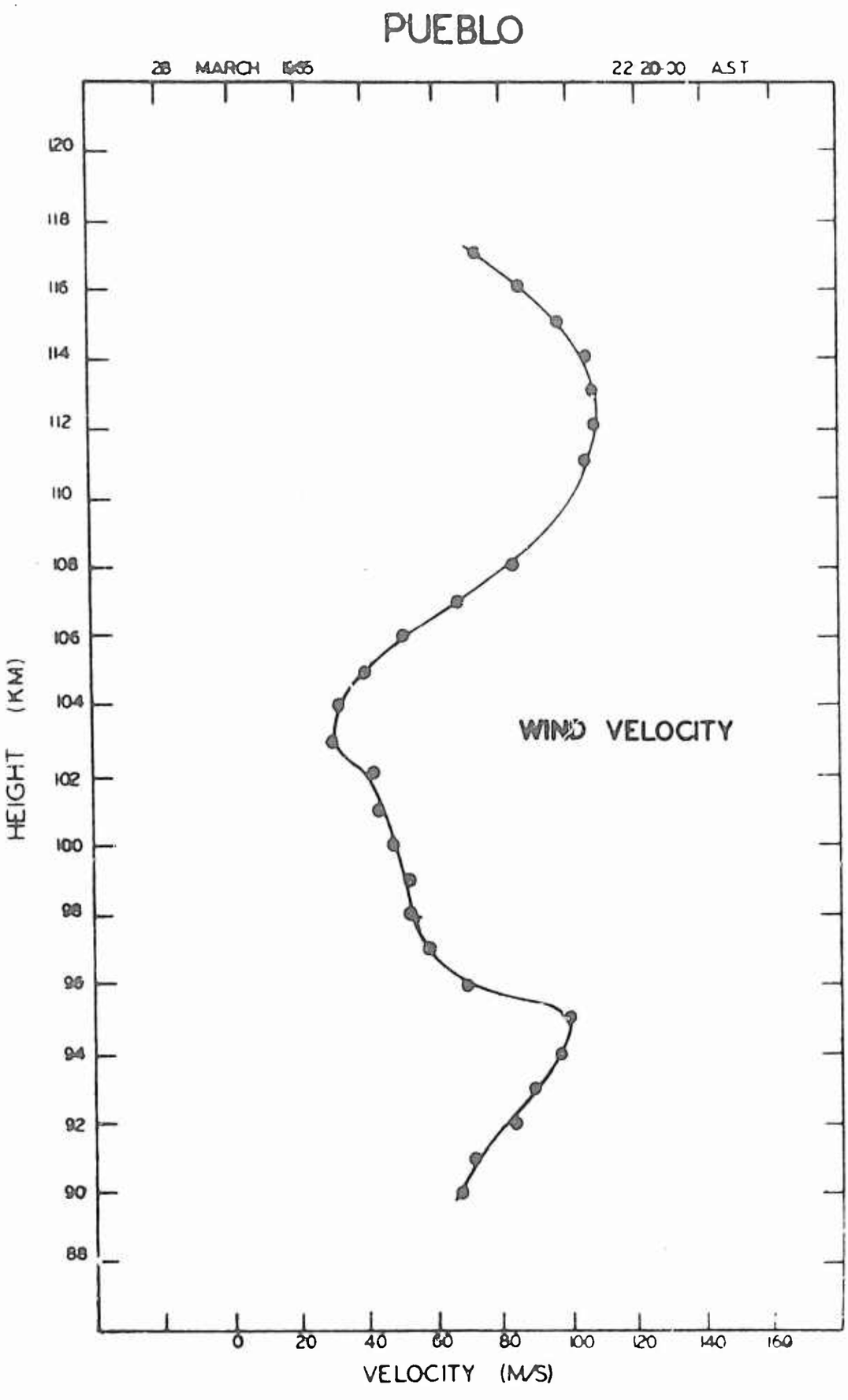
OTTAWA


28 MARCH 1965
20:01:50 AST
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
HEIGHT (KM)
WIND SHEAR COMPONENTS
N-S
E-W
-100
-80
-60
-40
-20
0
20
40
60
80
100
SHEAR (M / S / KM)

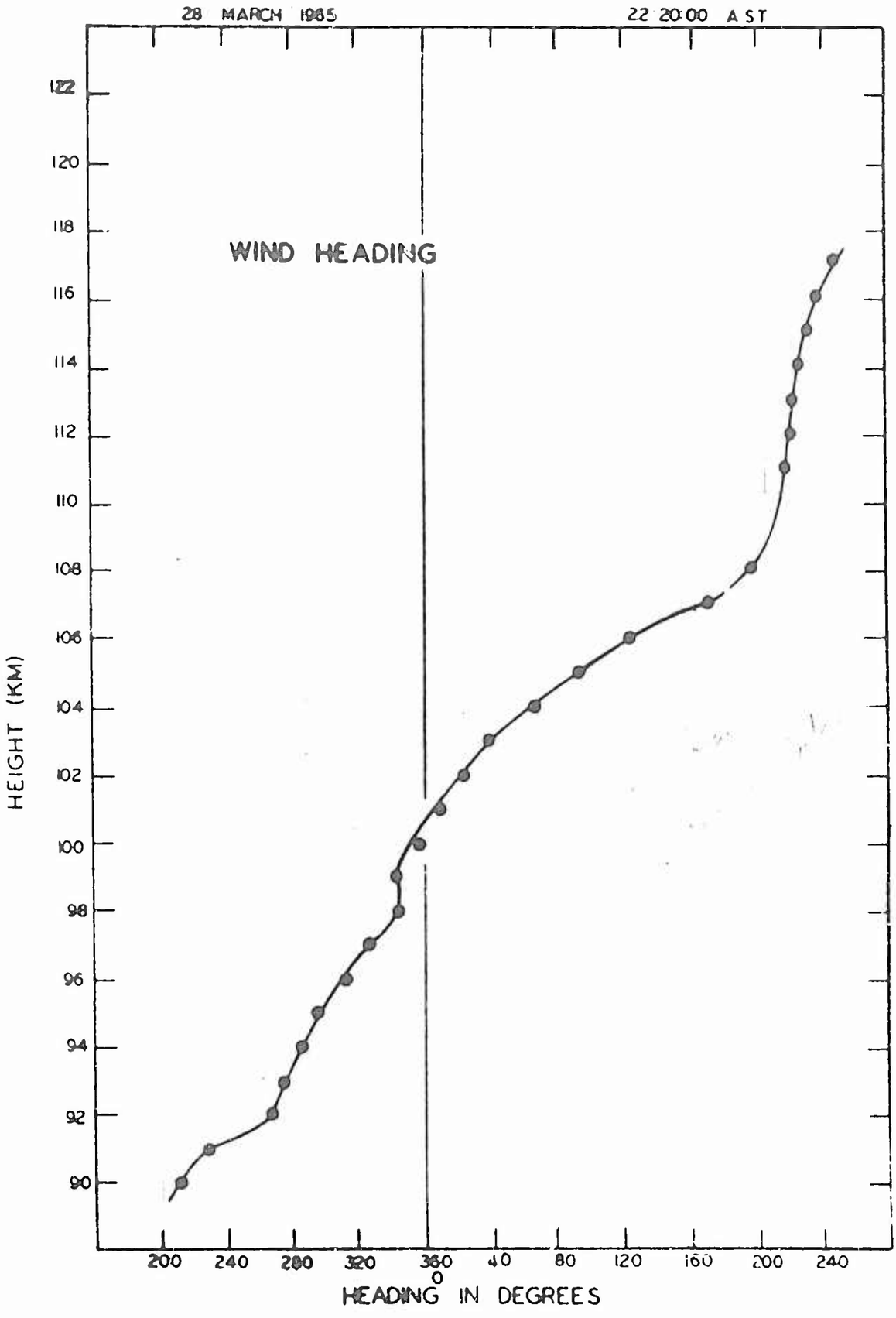
SHOT PUEBLO 28 MARCH 1965 22-20-00 AST

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
90.0	209.6	67.9	-59.0	-33.6
91.0	227.5	71.9	-48.6	-53.0
92.0	266.0	84.4	-5.9	-84.2
93.0	274.0	88.6	6.2	-88.3
94.0	286.0	96.7	26.6	-93.0
95.0	296.0	99.6	43.6	-89.5
96.0	313.6	70.3	48.5	-50.9
97.0	327.3	58.9	49.5	-31.8
98.0	345.6	52.6	51.0	-13.1
99.0	343.8	53.2	51.0	-14.8
100.0	356.4	48.3	48.2	-3.0
101.0	10.1	44.4	43.7	7.8
102.0	24.0	42.5	38.8	17.3
103.0	39.4	29.5	22.8	18.8
104.0	68.3	31.9	11.8	29.7
105.0	93.5	40.4	-2.5	40.3
106.0	123.5	51.3	-28.3	42.8
107.0	170.3	67.6	-66.7	11.4
108.0	196.9	84.5	-80.8	-24.6
111.0	217.6	105.3	-83.4	-64.2
112.0	220.6	108.1	-82.1	-70.4
113.0	223.1	107.4	-78.5	-73.3
114.0	226.9	106.1	-72.5	-77.5
115.0	232.8	98.1	-59.4	-78.1
116.0	239.4	85.7	-43.7	-73.8
117.0	248.6	73.9	-27.0	-68.7

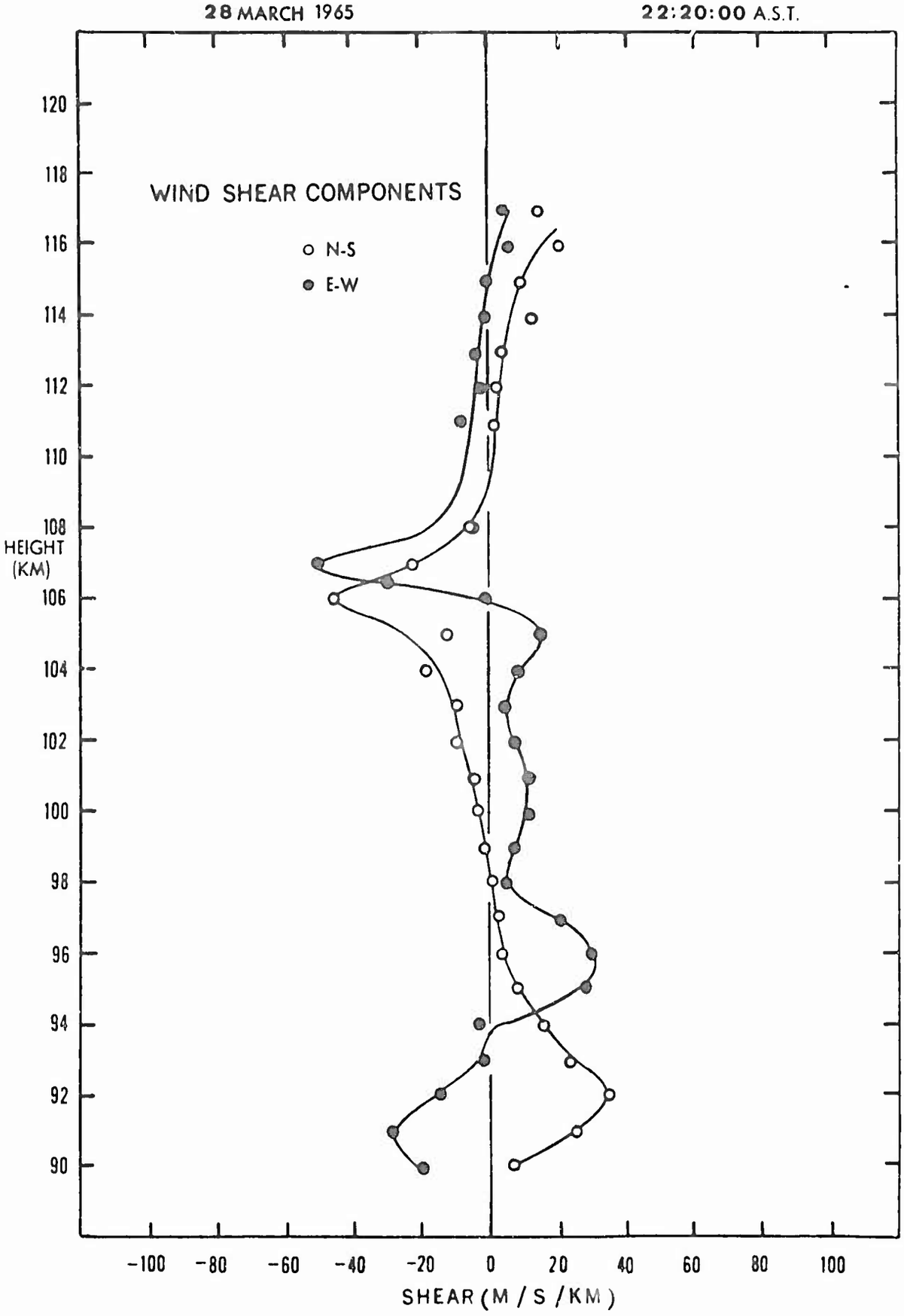

PUEBLO
28 MARCH 1965
22-20:00 A.S.T.
WIND COMPONENTS
O N-S
● E-W
HEIGHT (KM)
122
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
-120
-100
-80
-60
-40
-20
0
20
40
60
VELOCITY (M/S)


PUEBLO
28 MARCH 1965
22 20-00 AST
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
88
HEIGHT (KM)
WIND VELOCITY
0
20
40
60
80
100
120
140
160
VELOCITY (M/S)

PUEBLO


28 MARCH 1965
22 20:00 A S T
WIND HEADING
HEIGHT (KM)
122
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
200
240
280
320
360
40
80
120
160
200
240
HEADING IN DEGREES

PUEBLO


28 MARCH 1965
22:20:00 A.S.T.
WIND SHEAR COMPONENTS
N-S
E-W
HEIGHT (KM)
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
-100
-80
-60
-40
-20
0
20
40
60
80
100
SHEAR (M / S / KM)

SECTION III

SEVEN TRAIL RELEASES June 3-11, 1965

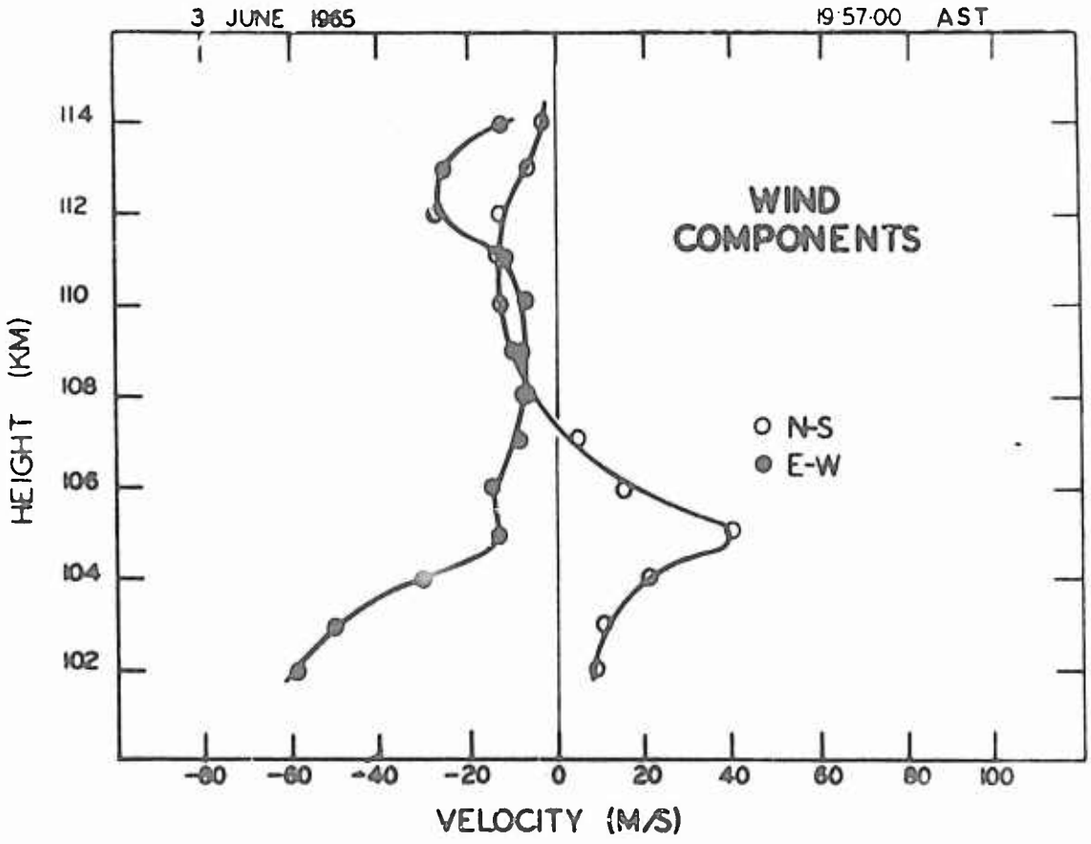
SHOT MARIUS 3 JUNE 1965 19-57-00 AST

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
102.0	279.5	59.3	9.7	-58.5
103.0	282.5	50.7	10.9	-49.5
104.0	306.7	37.2	22.2	-29.9
105.0	343.1	43.5	41.6	-12.7
106.0	313.0	21.6	16.1	-14.5
107.0	305.4	10.2	5.9	-8.3
108.0	229.8	10.2	-6.6	-7.8
109.0	219.4	12.5	-9.7	-8.0
110.0	211.6	14.0	-12.0	-7.3
111.0	219.8	17.1	-13.1	-11.0
112.0	245.3	29.9	-12.5	-27.2
113.0	256.6	25.6	-5.9	-24.9
114.0	258.4	12.7	-2.5	-12.4

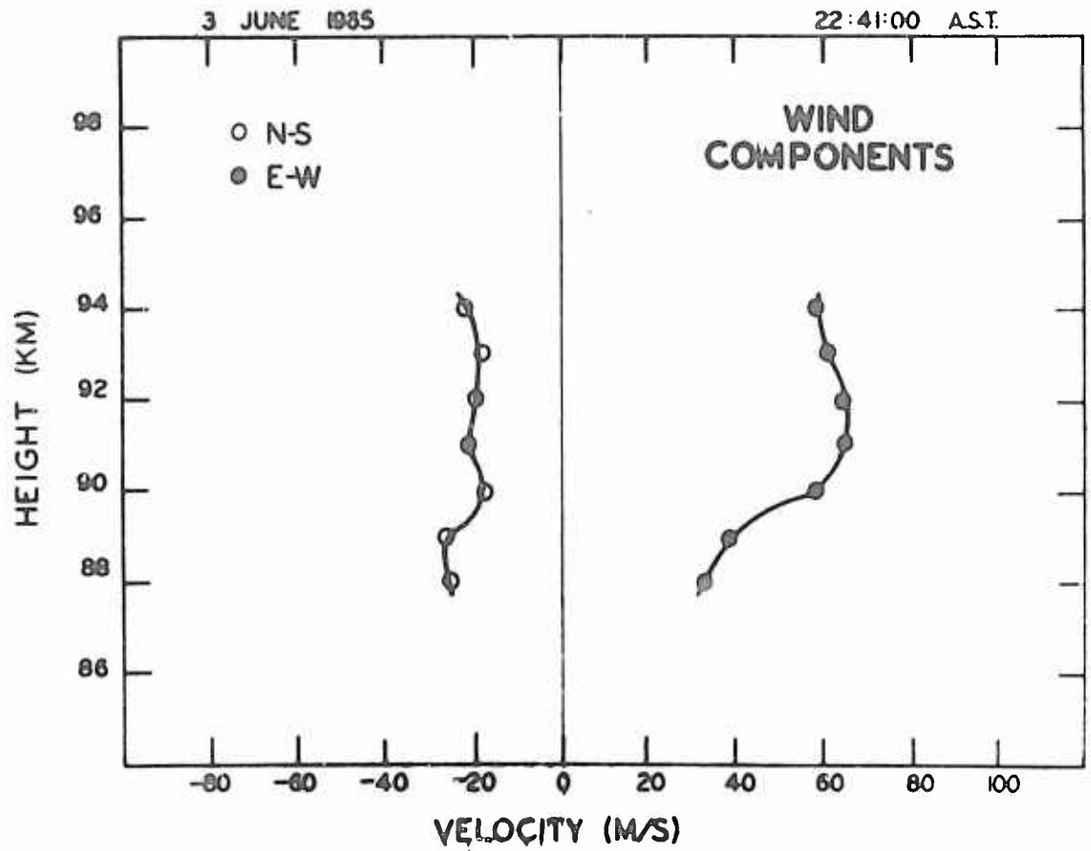
SHOT NERO 3 JUNE 1965 22-41-00 AST

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
88.0	127.0	41.9	-25.2	33.5
89.0	122.5	45.8	-24.6	38.7
90.0	106.3	61.0	-17.1	58.5
91.0	108.1	68.2	-21.2	64.9
92.0	106.7	67.0	-19.2	64.2
93.0	105.7	62.6	-17.0	60.3
94.0	109.2	62.9	-20.7	59.4

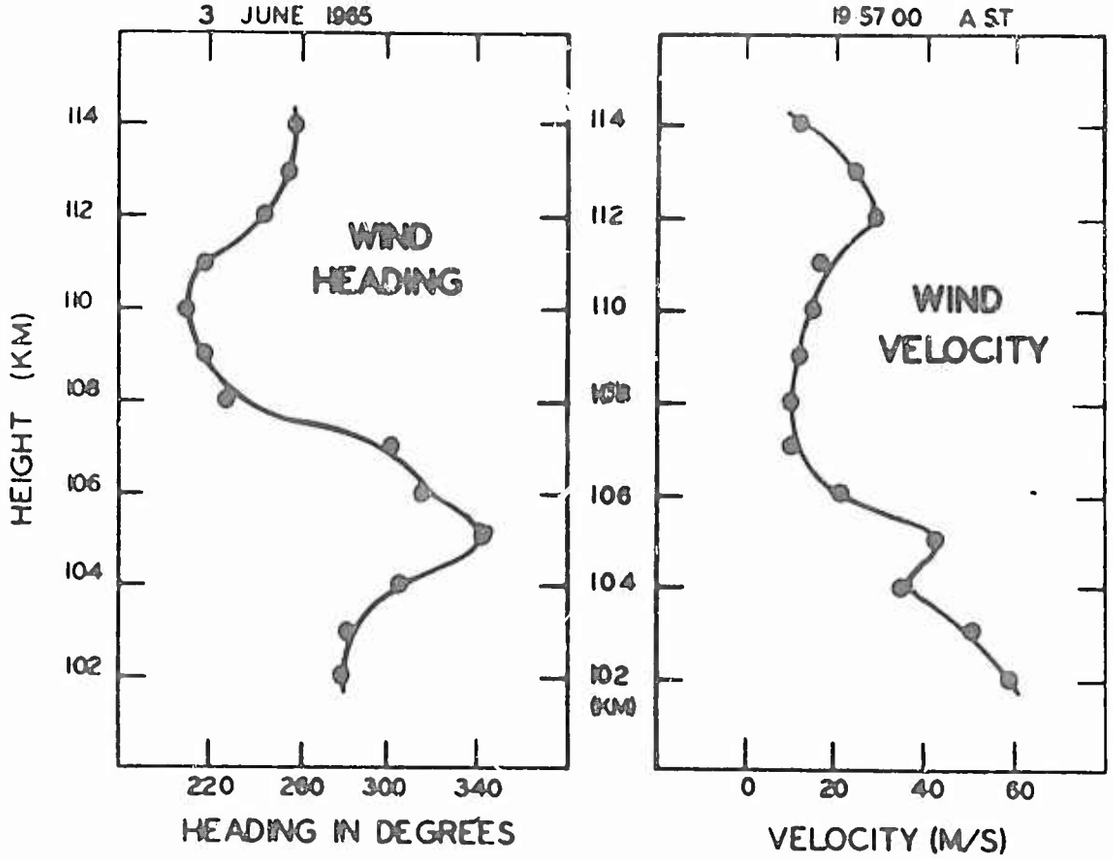
MARIUS


3 JUNE 1965
19:57:00 AST
WIND COMPONENTS
O N-S
● E-W
HEIGHT (KM)
114
112
110
108
106
104
102
-80 -60 -40 -20 0 20 40 60 80 100
VELOCITY (M/S)

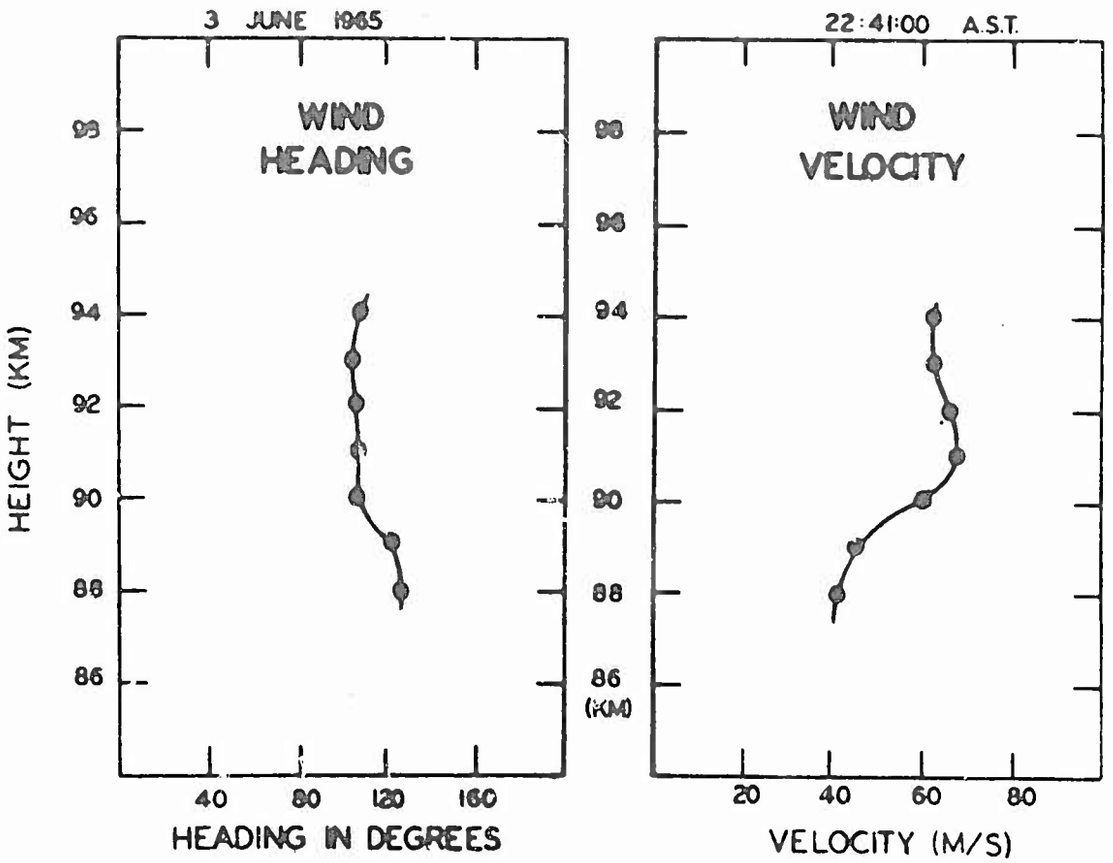
NERO


3 JUNE 1985
22:41:00 A.S.T.
O N-S
● E-W
WIND COMPONENTS
HEIGHT (KM)
98
96
94
92
90
88
86
-80 -60 -40 -20 0 20 40 60 80 100
VELOCITY (M/S)

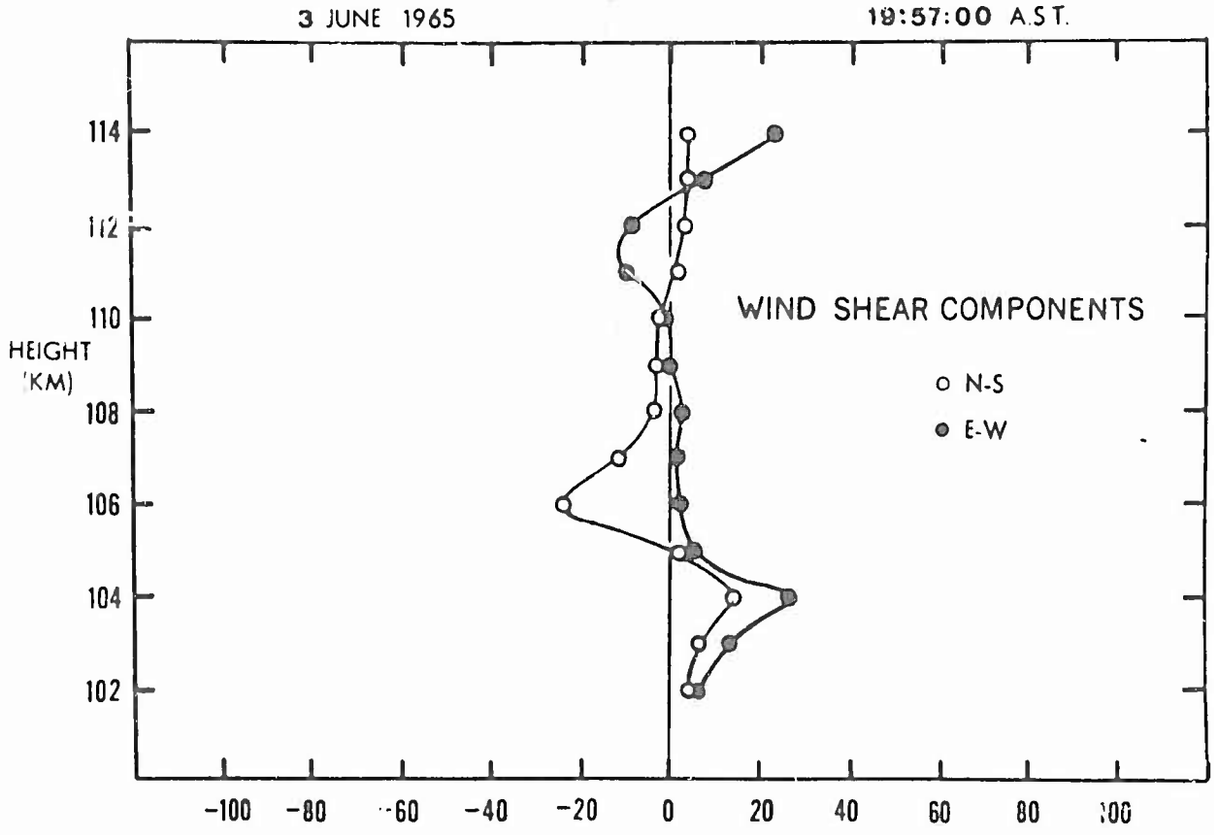
MARIUS


3 JUNE 1965
19 57 00 A.S.T.
WIND HEADING
WIND VELOCITY
HEIGHT (KM)
114
112
110
108
106
104
102
(KM)
220
260
300
340
HEADING IN DEGREES
0
20
40
60
VELOCITY (M/S)

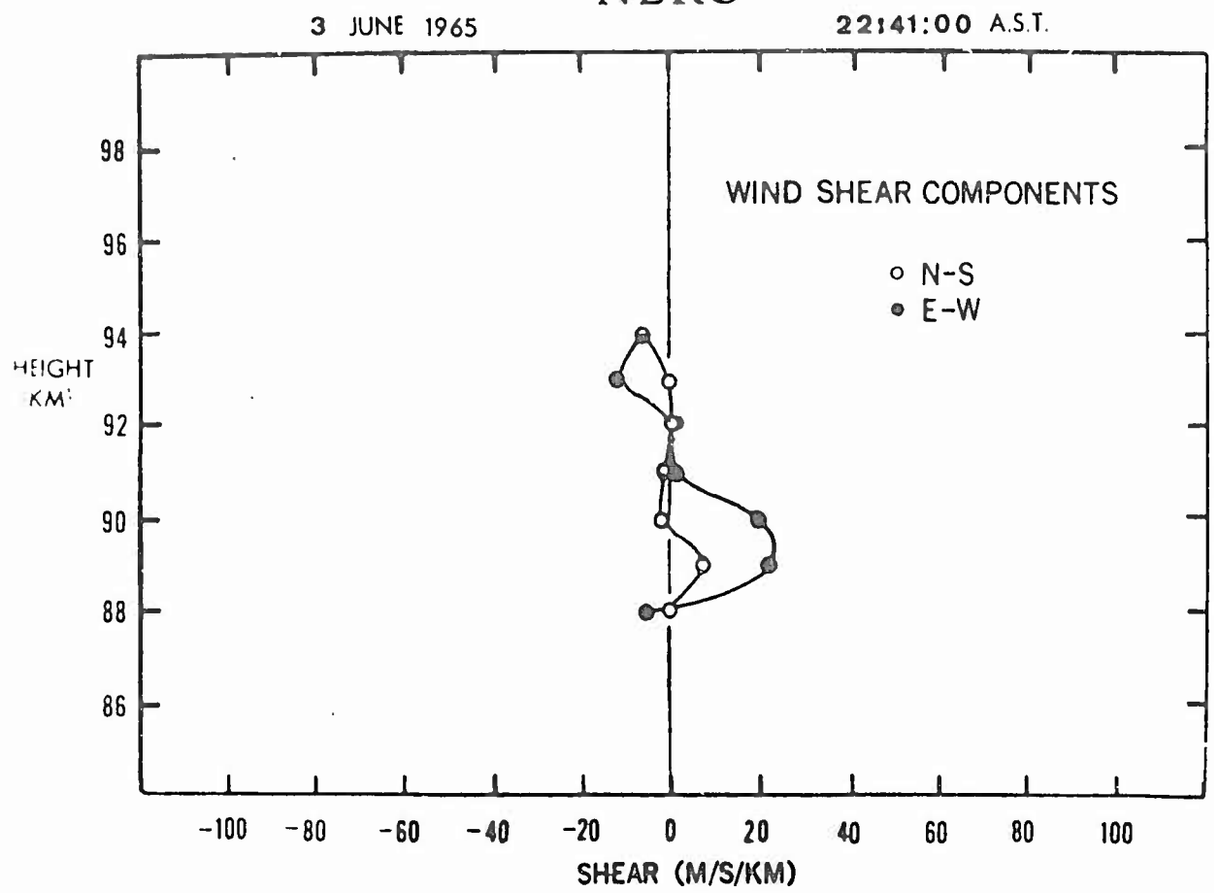
NERO


3 JUNE 1965
22:41:00 A.S.T.
WIND HEADING
WIND VELOCITY
HEIGHT (KM)
98
96
94
92
90
88
86
(KM)
40
80
120
160
HEADING IN DEGREES
20
40
60
80
VELOCITY (M/S)

MARIUS


3 JUNE 1965
19:57:00 A.S.T.
HEIGHT (KM)
114
112
110
108
106
104
102
WIND SHEAR COMPONENTS
N-S
E-W
-100
-80
-60
-40
-20
0
20
40
60
80
100

NERO


3 JUNE 1965
22:41:00 A.S.T.
HEIGHT (KM)
98
96
94
92
90
88
86
WIND SHEAR COMPONENTS
N-S
E-W
-100
-80
-60
-40
-20
0
20
40
60
80
100
SHEAR (M/S/KM)

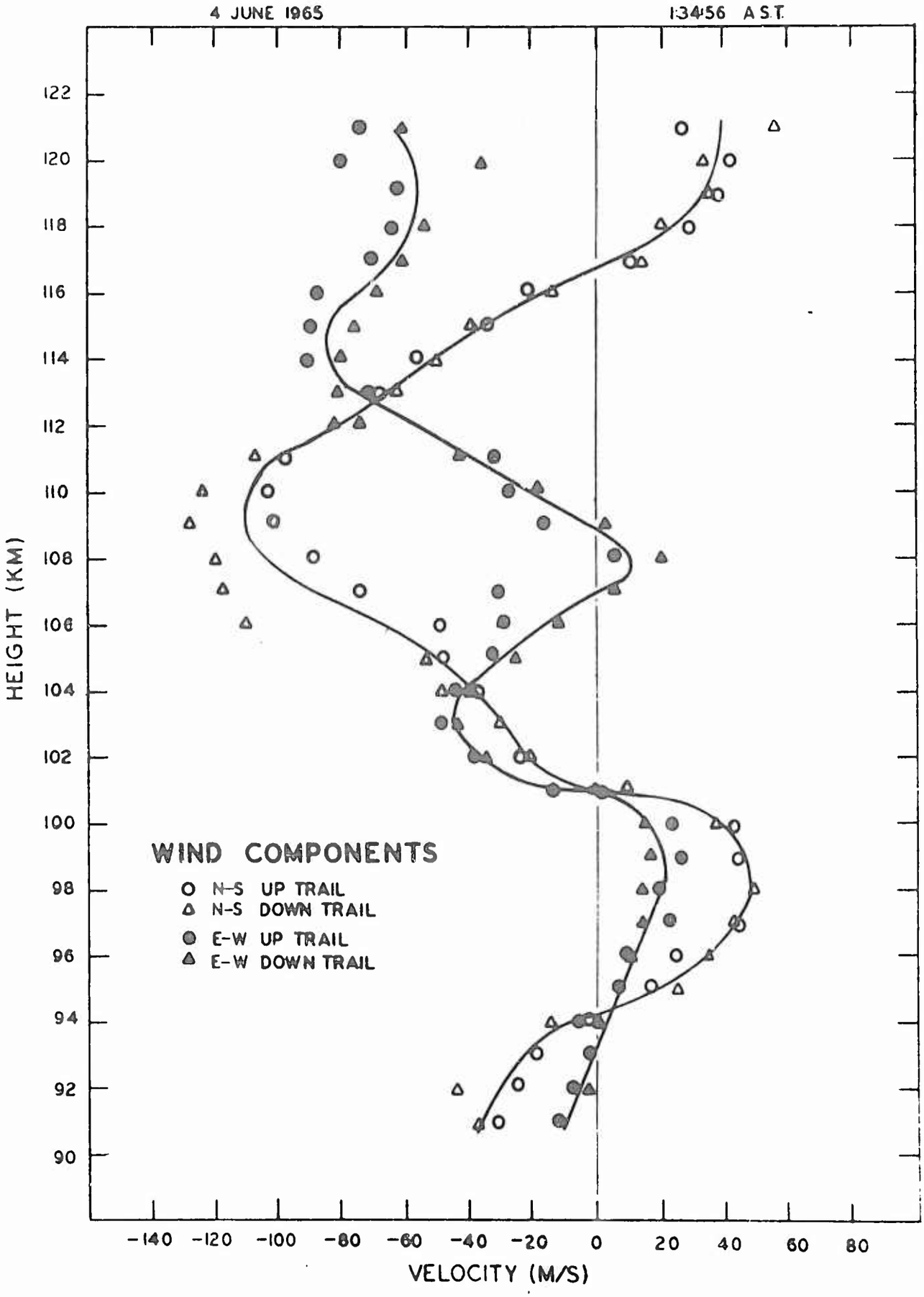
SHOT ELAGABULUS 4 JUNE 1965 01-34-56 AST
UP TRAIL

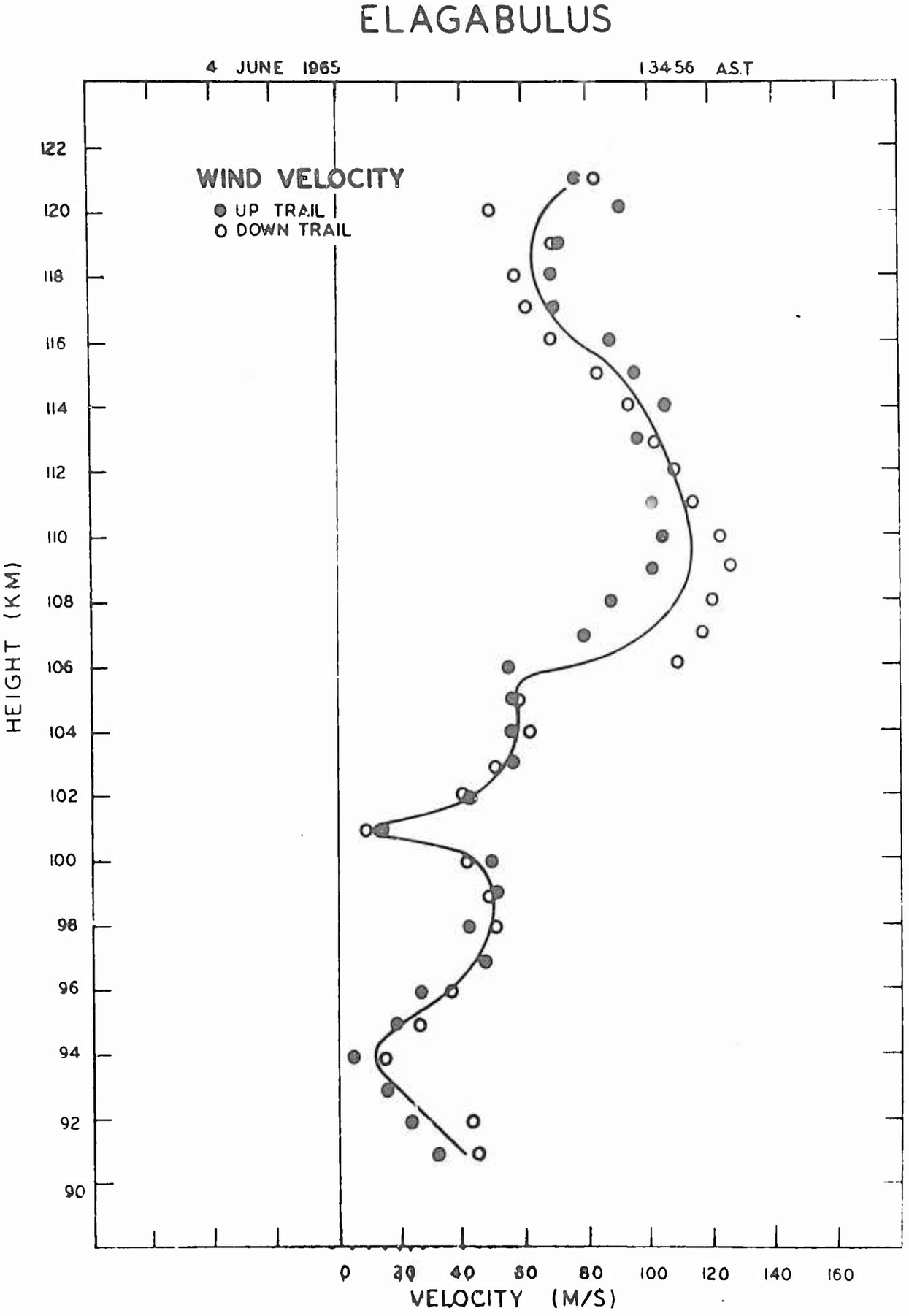
ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
91.0	201.4	30.2	-28.2	-11.0
92.0	195.6	23.6	-22.7	-6.3
93.0	185.9	15.8	-15.7	-1.6
94.0	259.0	4.8	-0.9	-4.7
95.0	25.8	19.0	17.1	8.3
96.0	21.0	26.7	25.0	9.6
97.0	25.0	47.9	43.4	20.3
98.0	26.1	42.9	38.5	18.9
99.0	30.1	52.4	45.4	26.3
100.0	27.5	50.0	44.3	23.1
101.0	281.3	14.5	2.9	-14.3
102.0	240.1	43.4	-21.6	-37.6
103.0	238.6	56.6	-29.5	-48.3
104.0	231.7	56.5	-35.0	-44.3
105.0	214.5	57.1	-47.1	-32.4
106.0	211.0	55.8	-47.8	-28.8
107.0	201.9	79.5	-73.8	-29.6
108.0	176.2	87.7	-87.5	5.8
109.0	189.1	101.2	-99.9	-16.0
110.0	194.1	105.4	-102.2	-25.7
111.0	197.8	100.9	-96.1	-30.8
113.0	226.5	96.8	-66.7	-70.2
114.0	238.4	105.5	-55.2	-89.9
115.0	249.7	94.8	-32.8	-89.0
116.0	256.9	87.8	-19.9	-85.5
117.0	279.7	70.7	11.9	-69.7
118.0	294.6	69.0	28.7	-62.7
119.0	302.8	71.6	38.8	-60.2
120.0	298.8	90.6	43.7	-79.4
121.0	291.3	77.8	28.2	-72.5

SHOT ELAGABULUS 4 JUNE 1965 01-34-56 AST
DOWN TRAIL

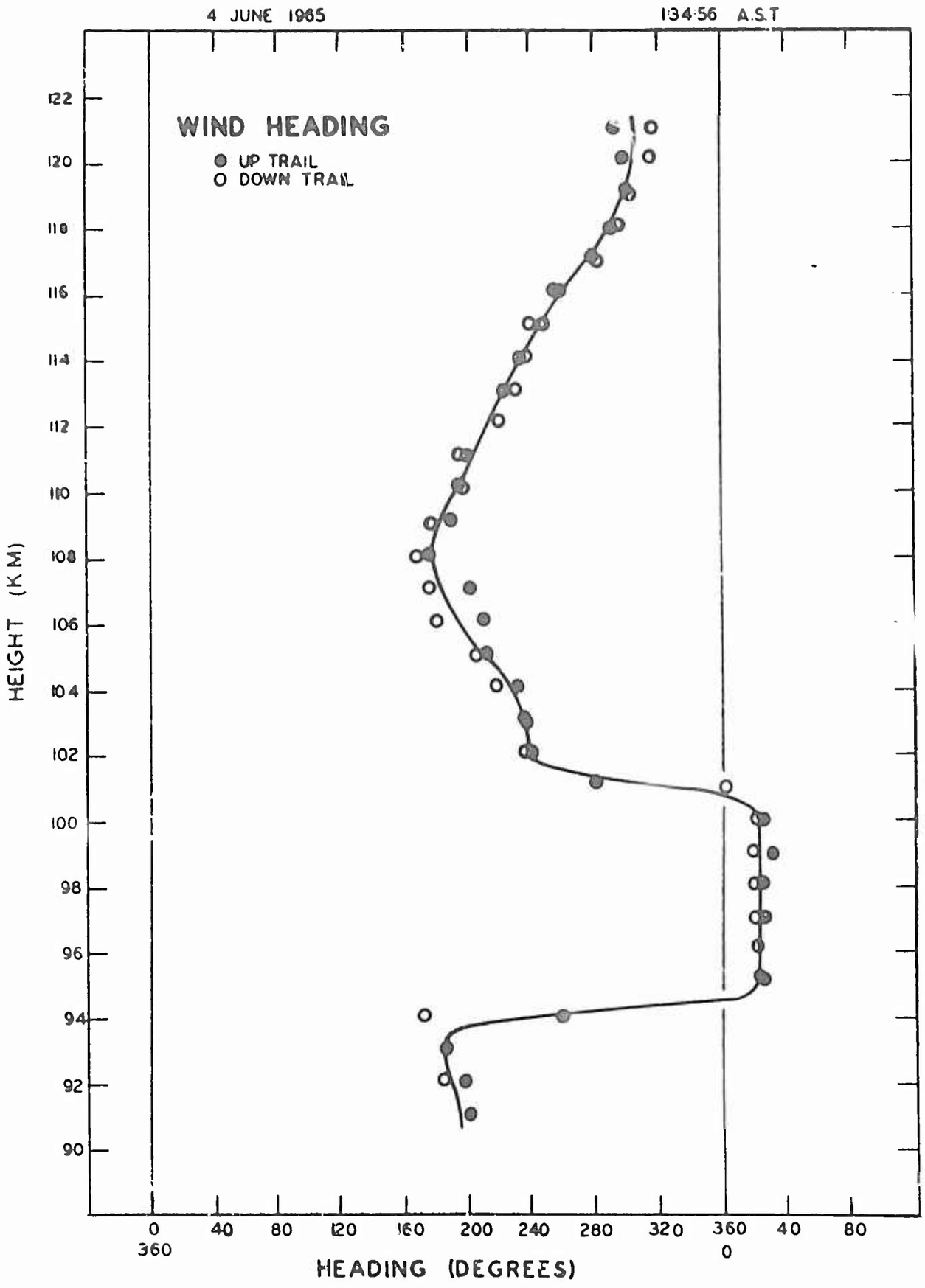
ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
91.0	143.4	45.6	-36.7	27.2
92.0	182.0	43.7	-43.7	-1.6
93.0	141.6	53.2	-41.7	33.1
94.0	172.3	14.8	-14.6	2.0
95.0	22.4	27.0	25.0	10.3
96.0	17.1	36.7	35.0	10.8
97.0	19.1	46.1	43.6	15.1
98.0	17.1	50.9	48.6	15.0
99.0	20.3	49.4	46.3	17.1
100.0	21.6	41.6	38.7	15.3
101.0	1.7	9.5	9.5	0.3
102.0	238.0	40.6	-21.5	-34.4
103.0	235.5	52.4	-29.7	-43.2
104.0	218.6	62.1	-48.6	-38.7
105.0	205.3	58.5	-52.9	-25.0
106.0	180.7	109.3	-109.3	-1.4
107.0	176.2	117.9	-117.6	7.7
108.0	170.3	120.9	-119.2	20.3
109.0	178.1	126.5	-126.4	4.1
110.0	187.6	123.1	-122.0	-16.3
111.0	201.2	114.2	-106.4	-41.3
112.0	221.8	108.6	-80.9	-72.4
113.0	232.5	101.9	-62.0	-80.8
114.0	237.7	94.0	-50.2	-79.5
115.0	242.8	83.3	-38.0	-74.1
116.0	259.3	69.1	-12.9	-67.9
117.0	284.1	61.9	15.1	-60.1
118.0	290.8	57.9	20.6	-54.1
119.0	301.3	70.3	36.5	-60.1
120.0	315.9	49.6	35.6	-34.5
121.0	313.8	83.4	57.7	-60.2

ELAGABULUS

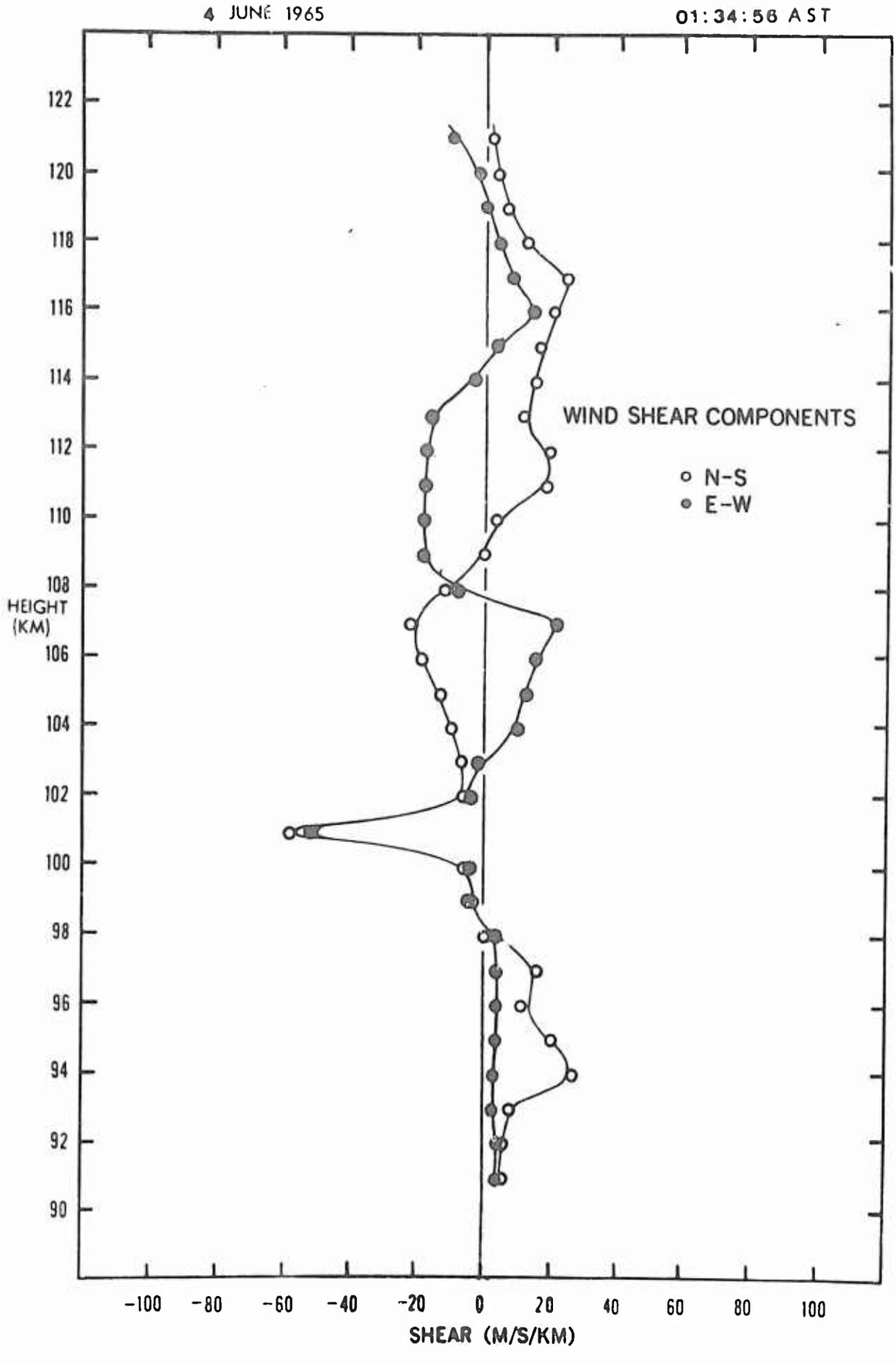

4 JUNE 1965
1:34:56 A.S.T.
HEIGHT (KM)
122
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
WIND COMPONENTS
N-S UP TRAIL
N-S DOWN TRAIL
E-W UP TRAIL
E-W DOWN TRAIL
-140 -120 -100 -80 -60 -40 -20 0 20 40 60 80
VELOCITY (M/S)


ELAGABULUS
4 JUNE 1965
1345-56 A.S.T
WIND VELOCITY
UP TRAIL
DOWN TRAIL
HEIGHT (KM)
122
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
0
20
40
60
80
100
120
140
160
VELOCITY (M/S)

ELAGABULUS


4 JUNE 1965
1345:56 A.S.T
WIND HEADING
UP TRAIL
DOWN TRAIL
HEIGHT (KM)
122
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
0
360
40
80
120
160
200
240
280
320
360
0
40
80
HEADING (DEGREES)

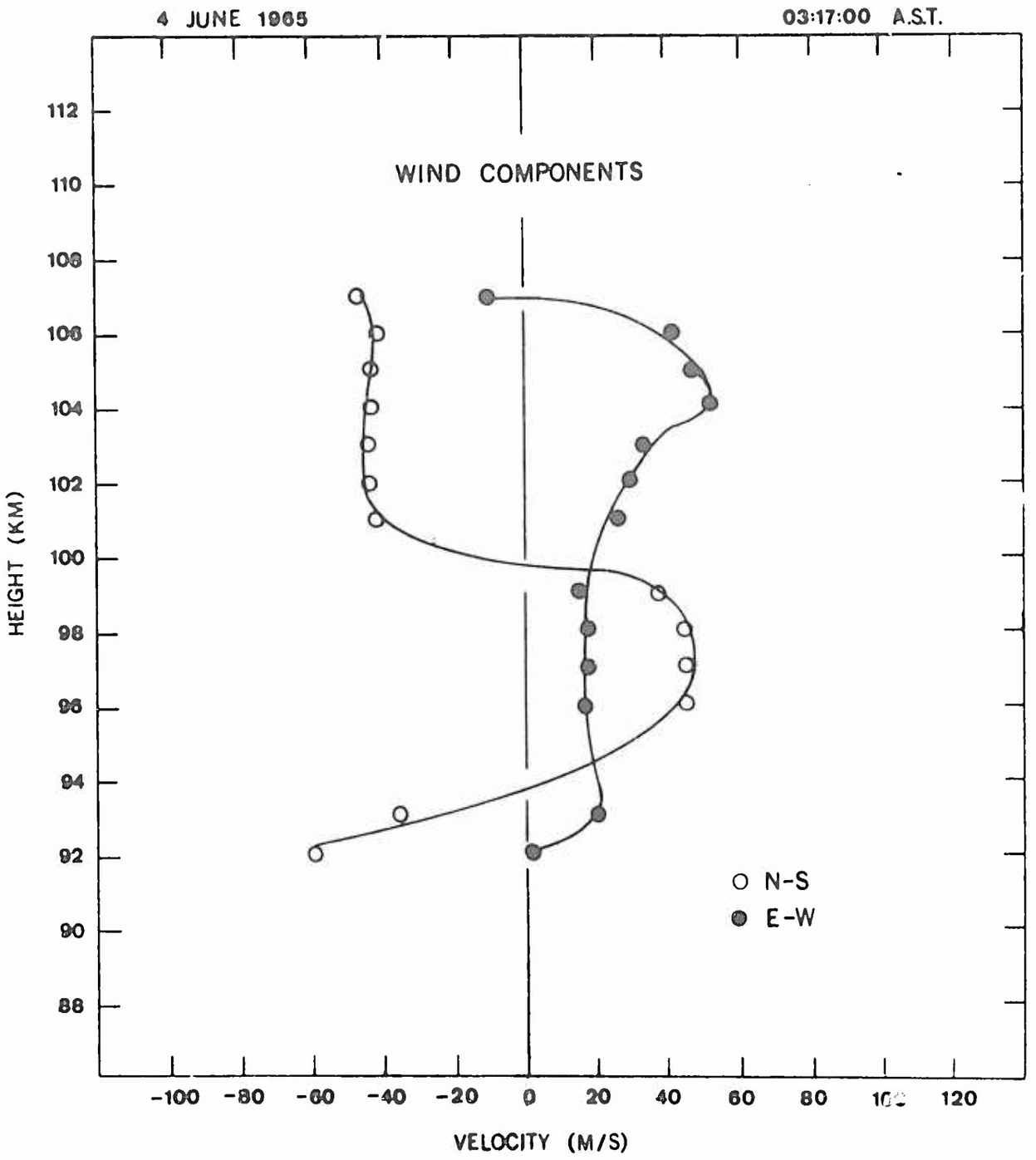
ELAGABULUS


4 JUNE 1965
01:34:56 AST
122
120
118
116
114
112
110
108
HEIGHT (KM)
106
104
102
100
98
96
94
92
90
WIND SHEAR COMPONENTS
N-S
E-W
-100
-80
-60
-40
-20
0
20
40
60
80
100
SHEAR (M/S/KM)

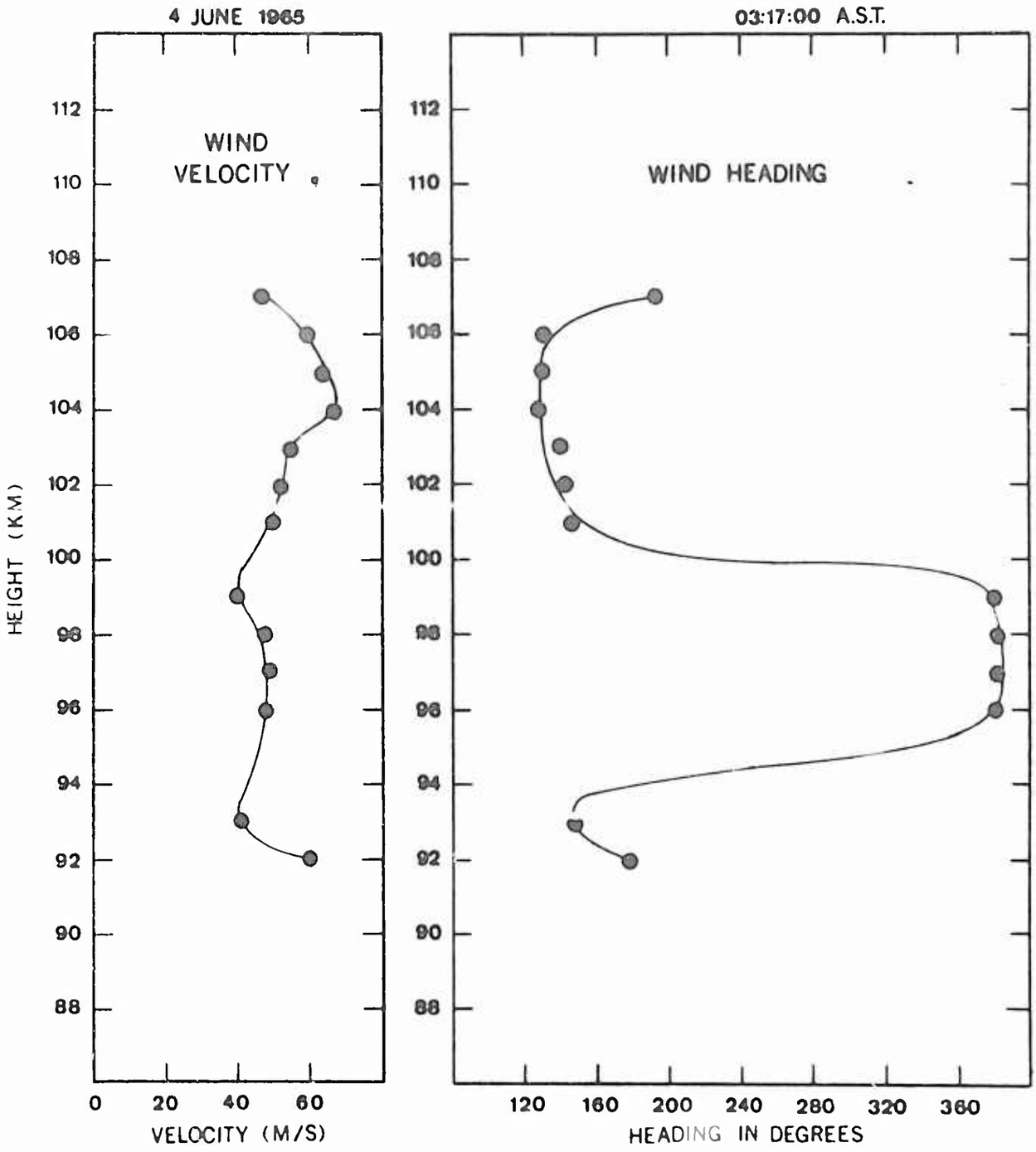
SHOT FABIUS 4 JUNE 1965 03-17-00 AST

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
92.0	179.0	59.8	-59.7	1.0
93.0	149.3	41.4	-35.6	21.2
96.0	21.1	48.3	45.1	17.4
97.0	21.8	49.4	45.9	18.3
98.0	21.6	48.9	45.5	18.0
99.0	21.0	40.0	37.3	14.3
101.0	146.9	49.6	-41.6	27.1
102.0	144.7	52.4	-42.8	30.2
103.0	141.2	55.2	-43.0	34.6
104.0	128.5	67.7	-42.2	53.0
105.0	132.1	63.8	-42.8	47.3
106.0	132.4	59.3	-40.0	43.8
107.0	193.1	47.2	-46.0	-10.7

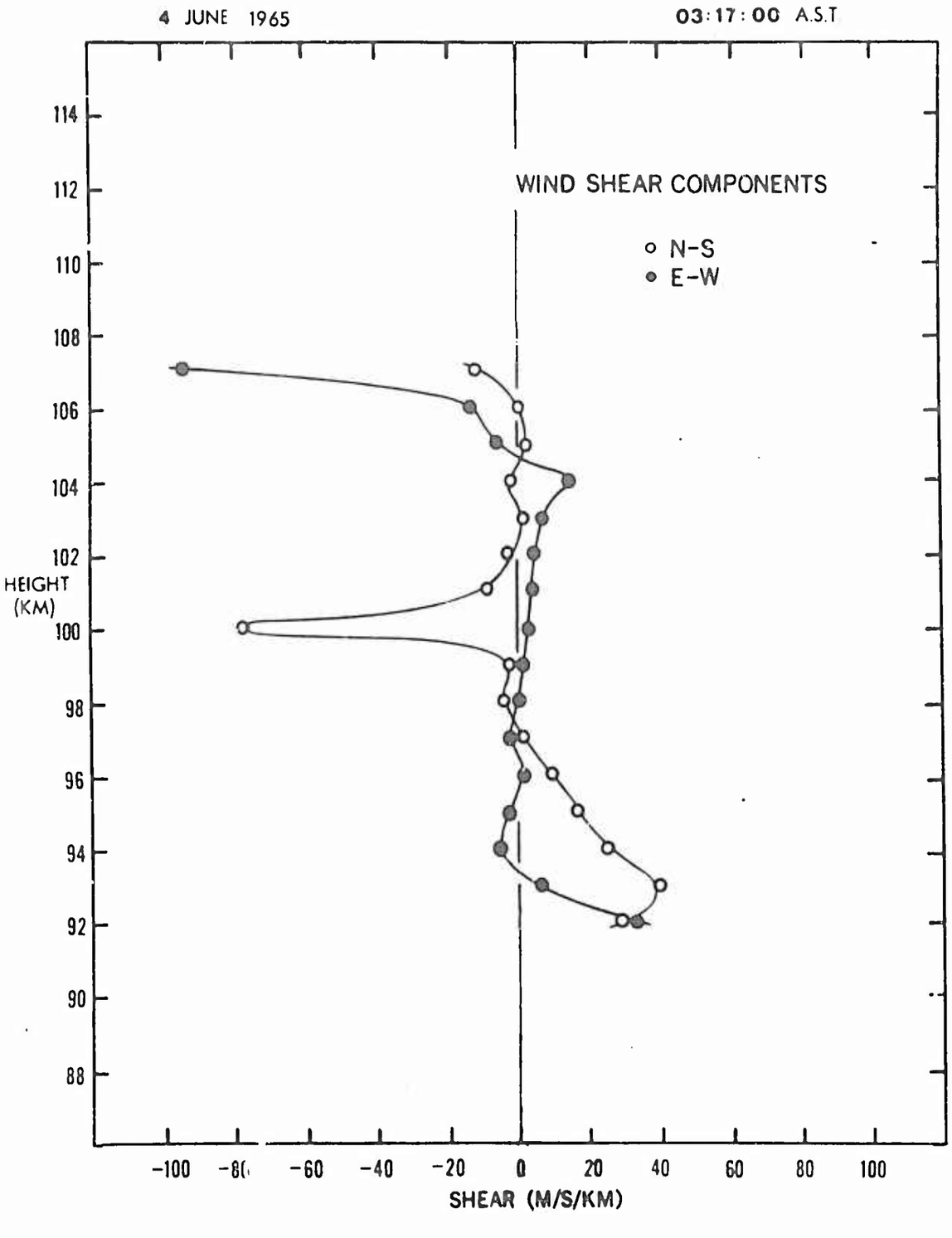
FABIUS


4 JUNE 1965
03:17:00 A.S.T.
WIND COMPONENTS
HEIGHT (KM)
112
110
108
106
104
102
100
98
96
94
92
90
88
-100
-80
-60
-40
-20
0
20
40
60
80
120
VELOCITY (M/S)
N-S
E-W

FABIUS


4 JUNE 1965
03:17:00 A.S.T.
WIND VELOCITY
WIND HEADING
HEIGHT (KM)
112
110
108
106
104
102
100
98
96
94
92
90
88
0
20
40
60
VELOCITY (M/S)
120
160
200
240
280
320
360
HEADING IN DEGREES

FABIUS


4 JUNE 1965
03:17:00 A.S.T
WIND SHEAR COMPONENTS
N-S
E-W
HEIGHT (KM)
114
112
110
108
106
104
102
100
98
96
94
92
90
88
-100
-80
-60
-40
-20
0
20
40
60
80
100
SHEAR (M/S/KM)

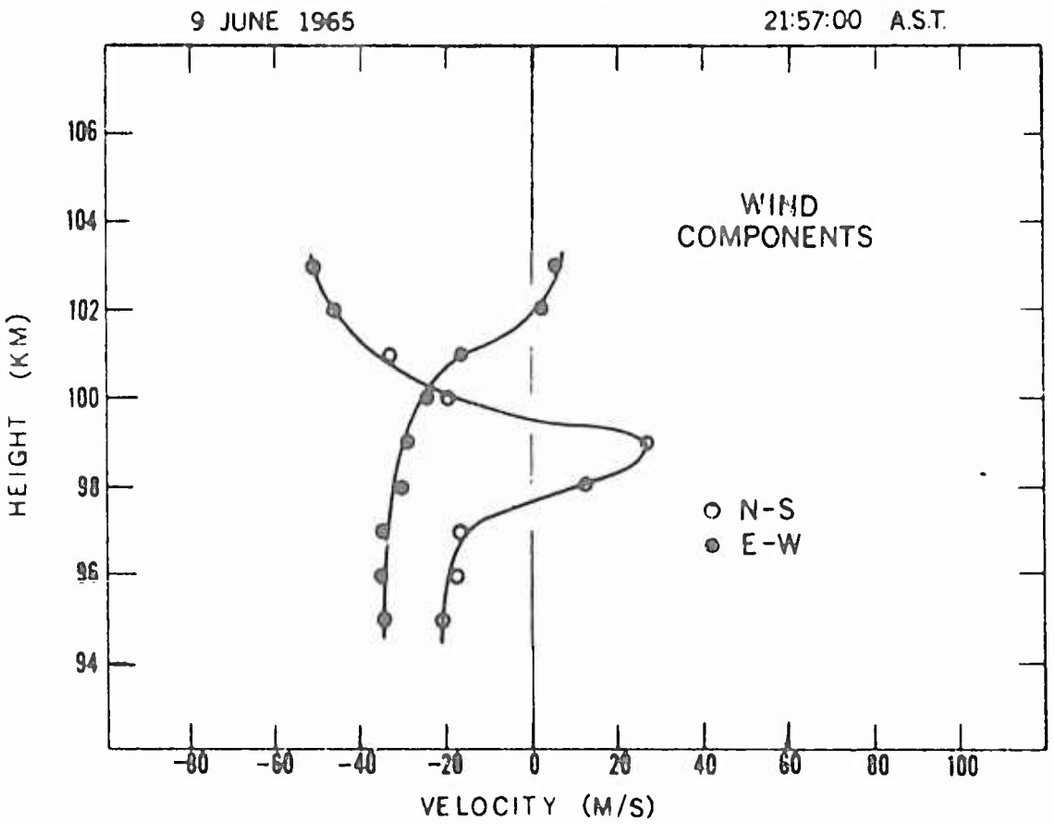
SHOT OVID 9 JUNE 1965 21-57-00 AST

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
95.0	238.3	39.7	-20.9	-33.8
96.0	243.9	39.0	-17.2	-35.1
97.0	243.9	39.2	-17.2	-35.3
98.0	296.4	33.2	14.7	-29.7
99.0	314.3	39.8	27.8	-28.5
100.0	230.9	30.4	-19.2	-23.6
101.0	206.6	36.5	-32.6	-16.4
102.0	176.4	46.5	-46.4	2.9
103.0	173.2	51.7	-51.3	6.1

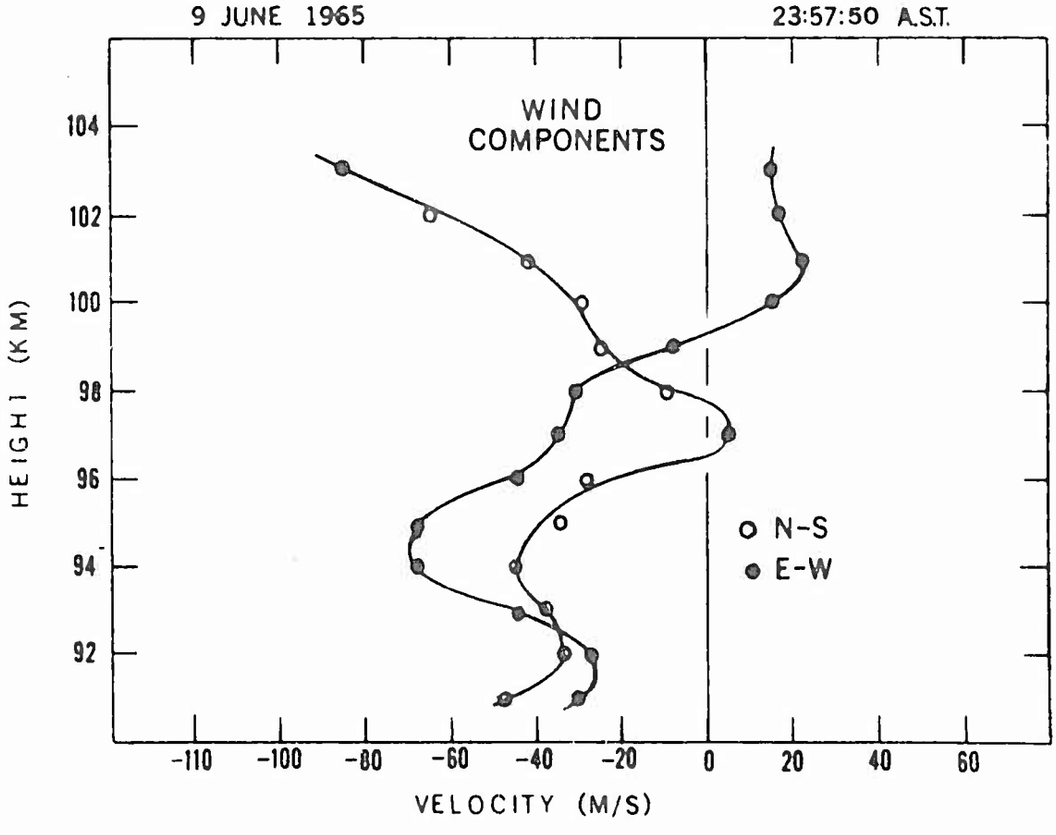
SHOT CICERO 9 JUNE 1965 23-57-50 AST

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
91.0	212.0	56.0	-47.5	-29.6
92.0	220.0	42.6	-32.7	-27.4
93.0	229.6	57.4	-37.2	-43.7
94.0	236.8	81.4	-44.6	-68.1
95.0	243.8	76.5	-33.8	-68.6
96.0	237.3	52.0	-28.1	-43.8
97.0	277.8	35.8	4.8	-35.5
98.0	254.6	31.9	-8.5	-30.8
99.0	197.1	26.0	-24.9	-7.7
100.0	151.9	32.7	-28.8	15.4
101.0	152.2	48.0	-42.4	22.4
102.0	165.3	67.2	-65.0	17.0
103.0	170.0	86.7	-85.4	15.0

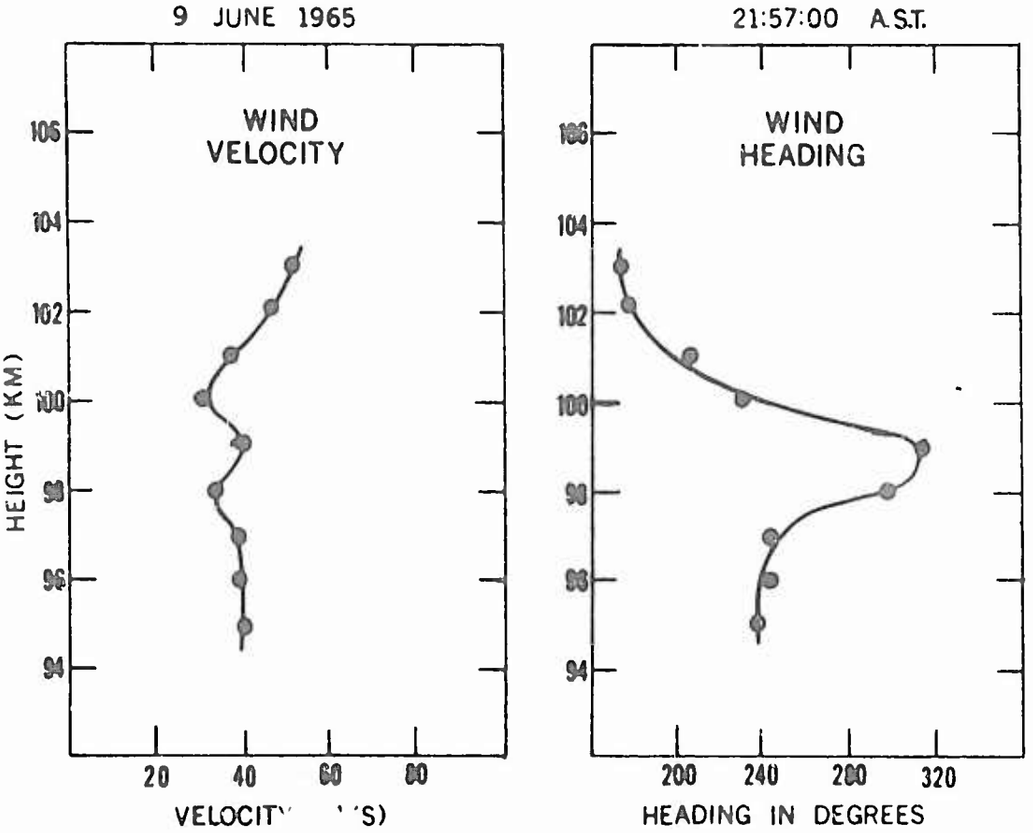
OVID


9 JUNE 1965
21:57:00 A.S.T.
WIND
COMPONENTS
N-S
E-W
HEIGHT (KM)
106
104
102
100
98
96
94
-80
-60
-40
-20
0
20
40
60
80
100
VELOCITY (M/S)

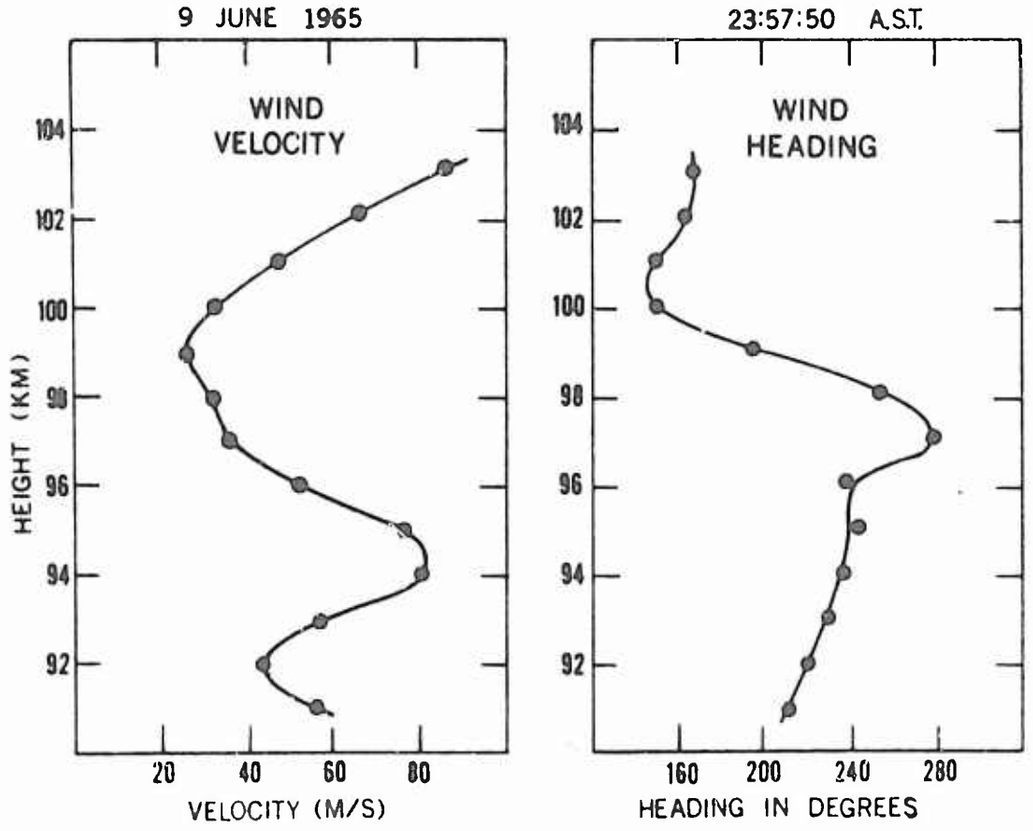
CICERO


9 JUNE 1965
23:57:50 A.S.T.
WIND
COMPONENTS
N-S
E-W
HEIGHT (KM)
104
102
100
98
96
94
92
-110
-100
-80
-60
-40
-20
0
20
40
60
VELOCITY (M/S)

OVID

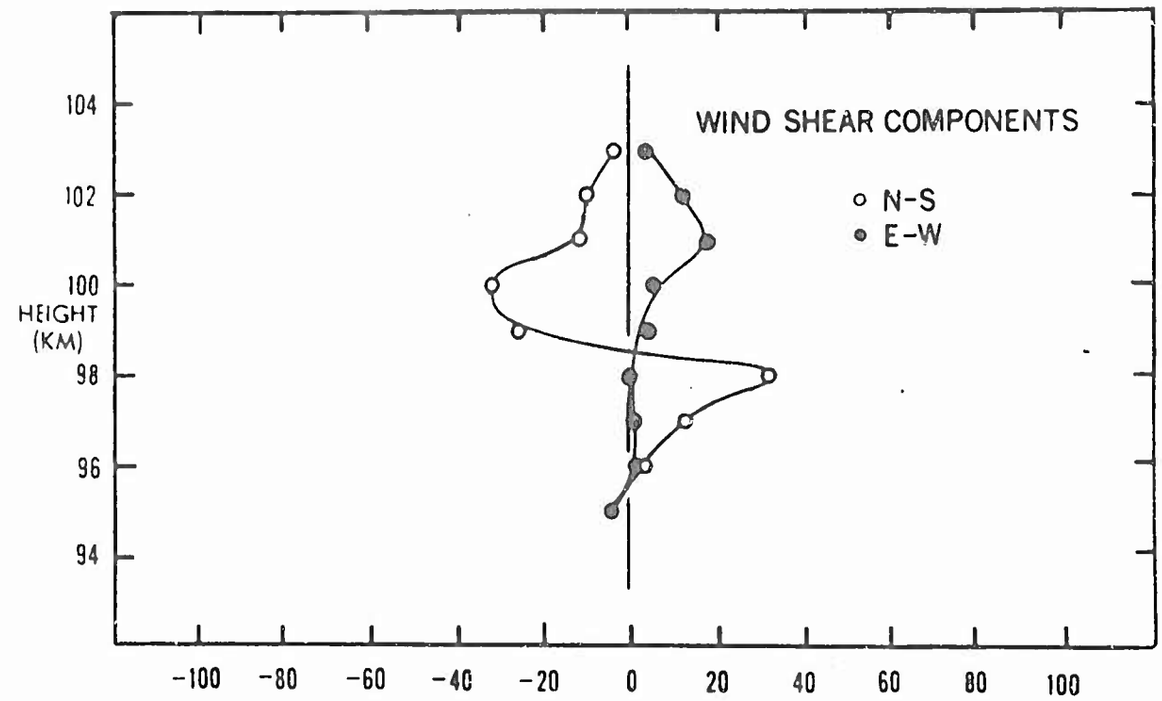

9 JUNE 1965
21:57:00 A.S.T.
WIND VELOCITY
WIND HEADING
HEIGHT (KM)
106
104
102
100
98
96
94
20
40
60
80
200
240
280
320
HEADING IN DEGREES

CICERO


9 JUNE 1965
23:57:50 A.S.T.
WIND VELOCITY
WIND HEADING
HEIGHT (KM)
104
102
100
98
96
94
92
20
40
60
80
160
200
240
280
VELOCITY (M/S)
HEADING IN DEGREES

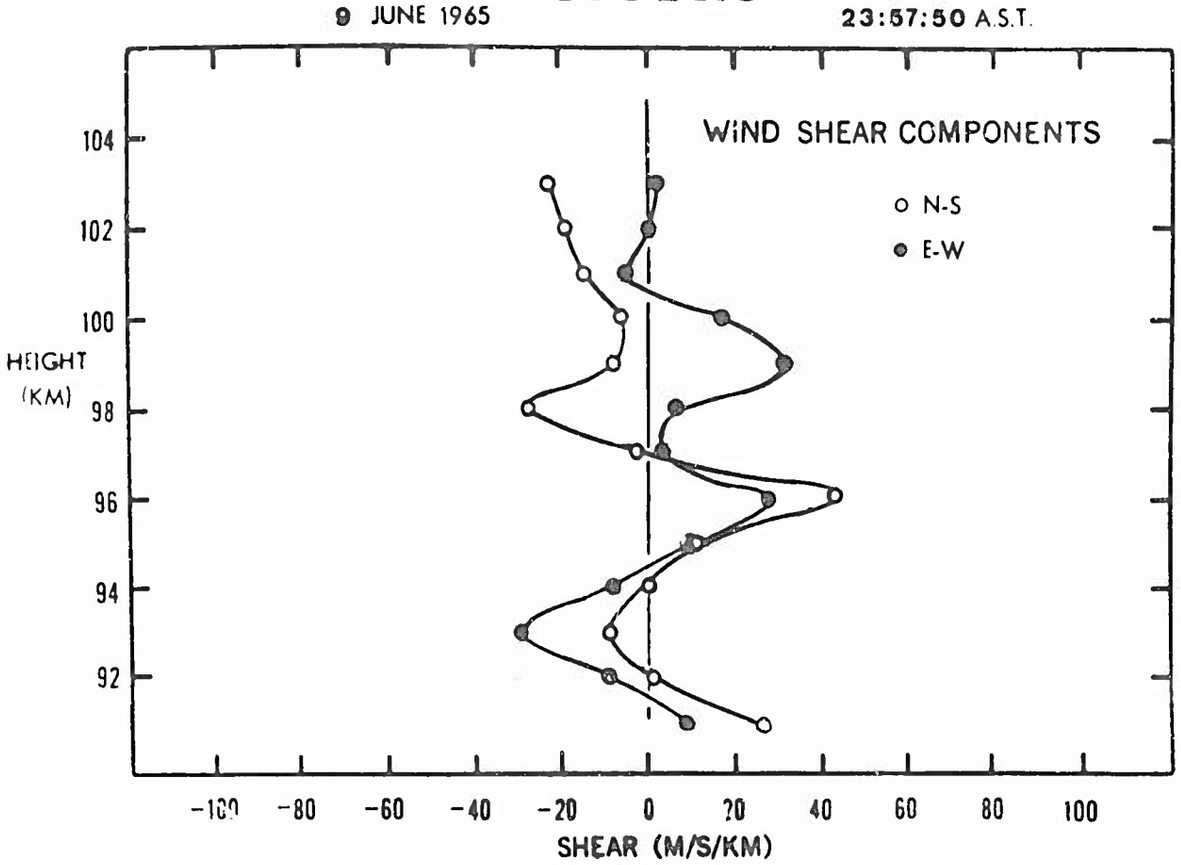
OVID

9 JUNE 1965 21:57:00 A.S.T.



CICERO

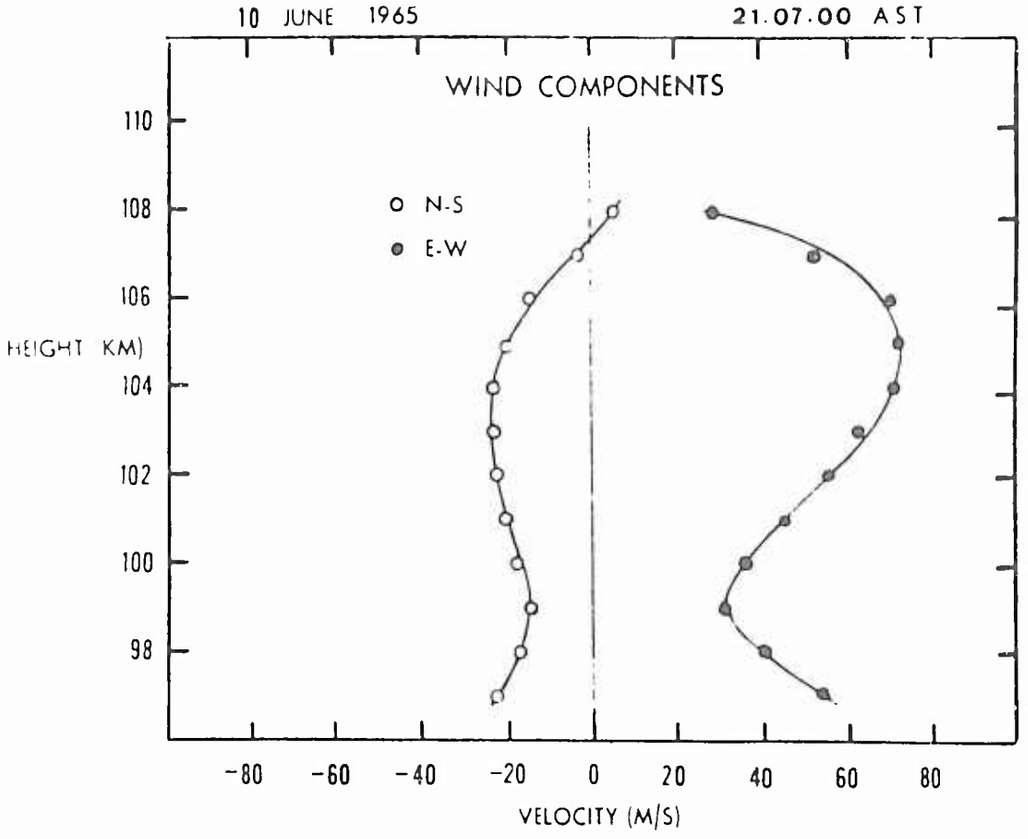
9 JUNE 1965 23:57:50 A.S.T.

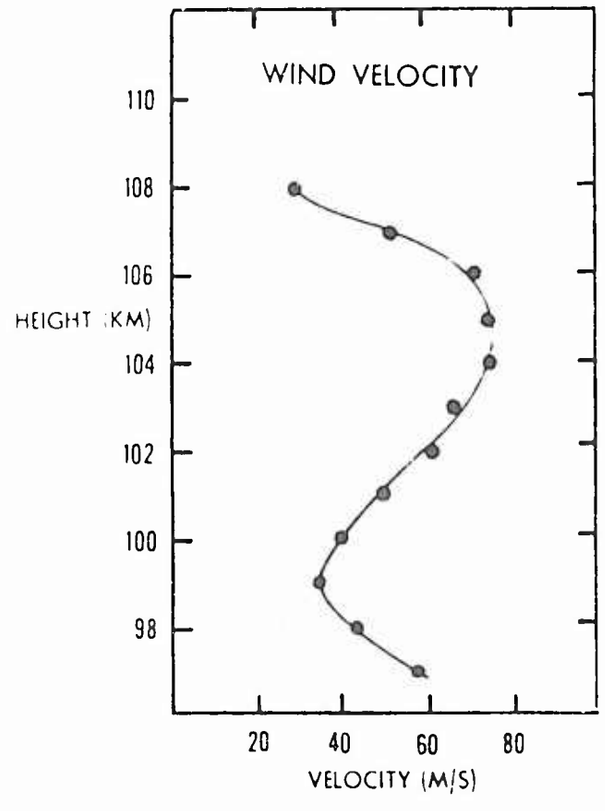


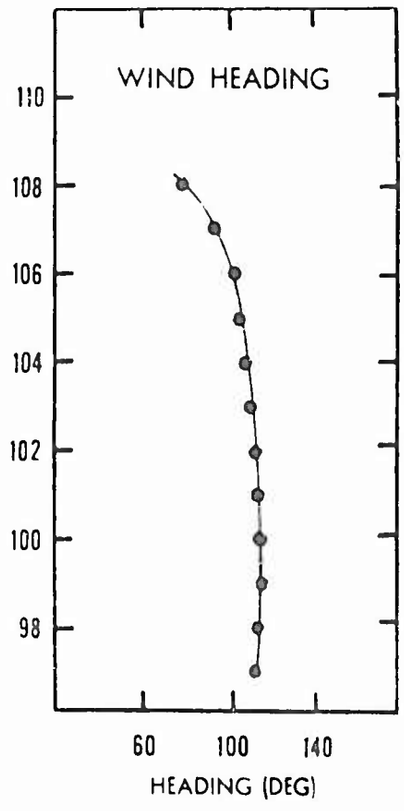
SHOT PLINY 10 JUNE 1965 21-07-00 AST

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
97.0	112.1	58.8	-22.2	54.5
98.0	113.7	44.4	-17.8	40.6
99.0	116.0	35.7	-15.7	32.1
100.0	116.4	40.9	-18.2	36.6
101.0	114.2	50.4	-20.7	45.9
102.0	112.5	62.2	-23.7	57.4
103.0	110.8	67.3	-23.8	62.9
104.0	108.6	75.8	-24.1	71.8
105.0	105.9	75.2	-20.5	72.3
106.0	102.0	71.9	-15.0	70.4
107.0	93.1	52.3	-2.8	52.3
108.0	79.0	30.1	5.8	29.6

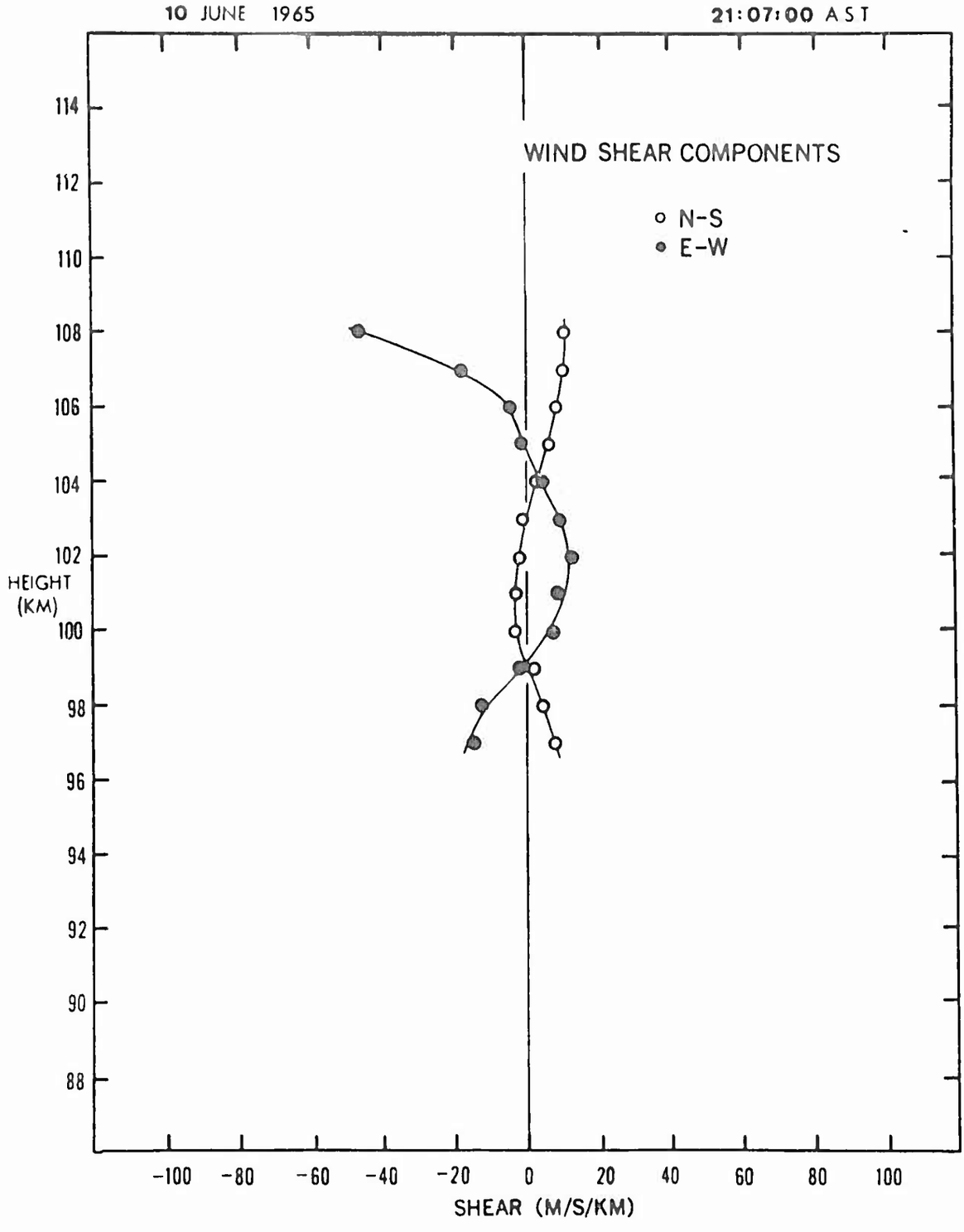
PLINY


10 JUNE 1965
21.07.00 AST
WIND COMPONENTS
N-S
E-W
HEIGHT (KM)
110
108
106
104
102
100
98
-80
-60
-40
-20
0
20
40
60
80
VELOCITY (M/S)


WIND VELOCITY
HEIGHT (KM)
110
108
106
104
102
100
98
20
40
60
80
VELOCITY (M/S)


WIND HEADING
110
108
106
104
102
100
98
60
100
140
HEADING (DEG)

PLINY


10 JUNE 1965
21:07:00 AST
WIND SHEAR COMPONENTS
N-S
E-W
HEIGHT (KM)
114
112
110
108
106
104
102
100
98
96
94
92
90
88
-100
-80
-60
-40
-20
0
20
40
60
80
100
SHEAR (M/S/KM)

SECTION IV

TWO TRAIL RELEASES August 5-6, 1965

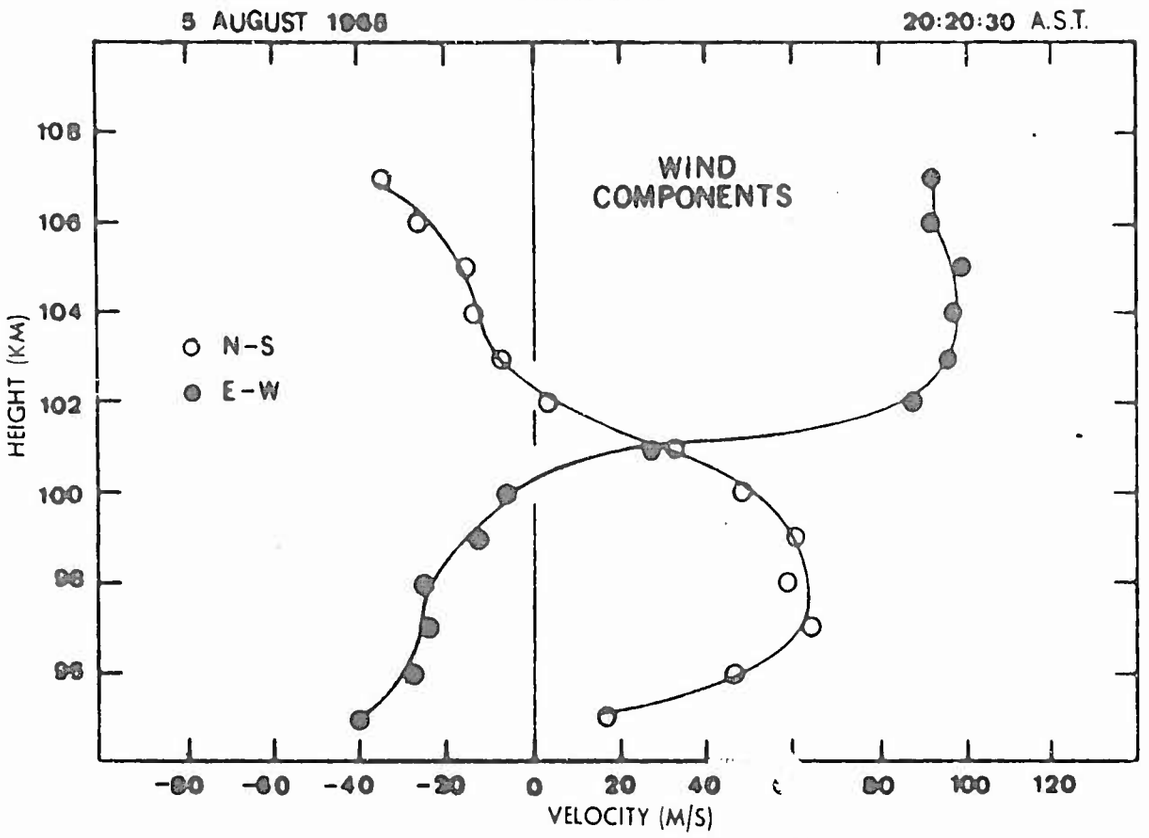
SHOT TIBERIUS 5 AUGUST 1965 20-2[illegible]-00 AST

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
95.0	292.6	43.6	16.8	-40.2
96.0	330.0	53.8	46.6	-26.9
97.0	340.7	69.0	65.1	-22.8
98.0	336.9	63.9	58.8	-25.1
99.0	349.4	62.2	61.1	-11.5
100.0	352.8	49.2	48.8	-6.[illegible]
101.0	[illegible].2	43.7	33.4	28.3
102.0	88.0	88.5	3.0	88.4
103.0	94.5	95.9	-7.5	95.6
104.0	97.9	97.8	-13.5	96.9
105.0	98.8	100.2	-15.4	99.0
106.0	105.8	94.9	-25.9	91.3
107.0	110.0	98.5	-33.7	92.5

SHOT UMBRIA 6 AUGUST 1965 02-44-00 AST

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) N-S	E-W
94.0	9.7	98.6	97.2	16.6
95.0	26.6	46.6	41.7	20.9
96.0	80.1	58.9	10.1	58.1
97.0	98.8	93.6	-14.3	92.5
98.0	101.3	110.6	-21.7	108.4
99.0	102.7	113.3	-24.9	110.5
100.0	108.1	123.4	-38.3	117.3
101.0	113.8	125.8	-50.9	115.1
102.0	114.7	128.8	-53.9	117.0
103.0	112.9	127.7	-49.6	117.6
104.0	109.0	128.3	-41.7	121.3
105.0	108.7	131.0	-41.9	124.1
106.0	105.6	145.3	-39.0	140.0

TIBERIUS



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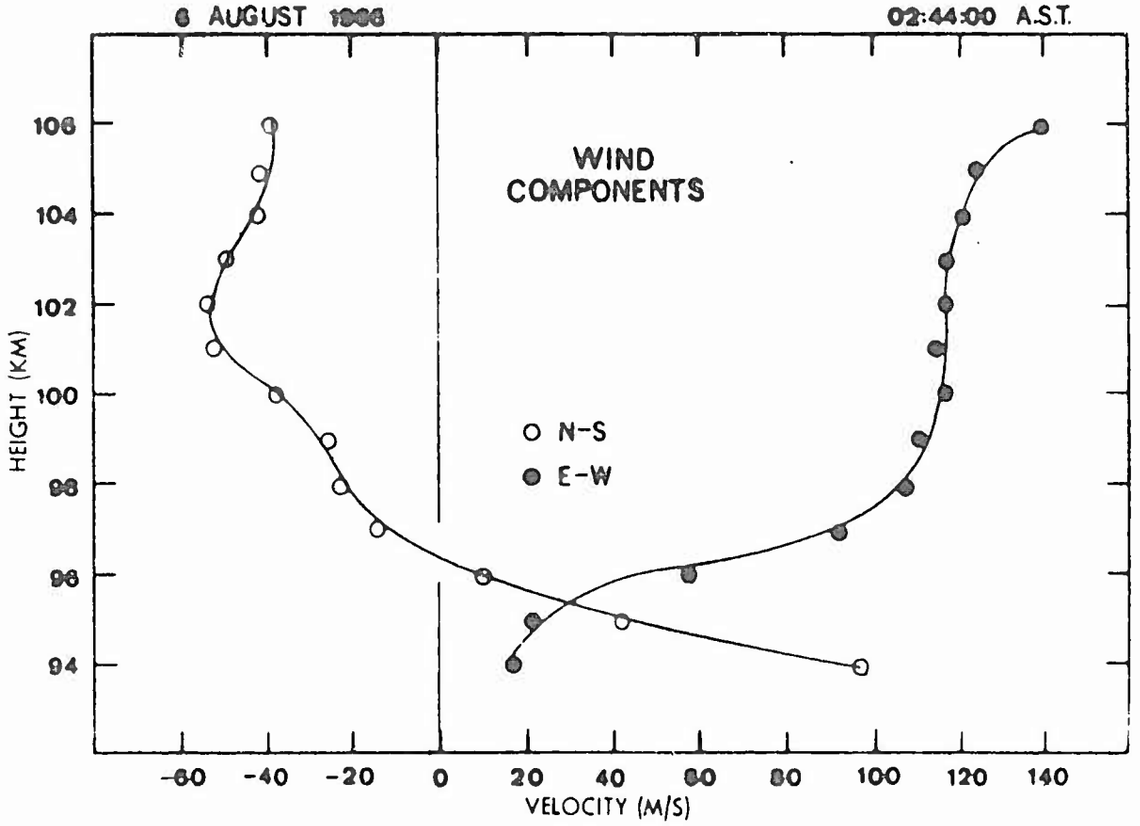

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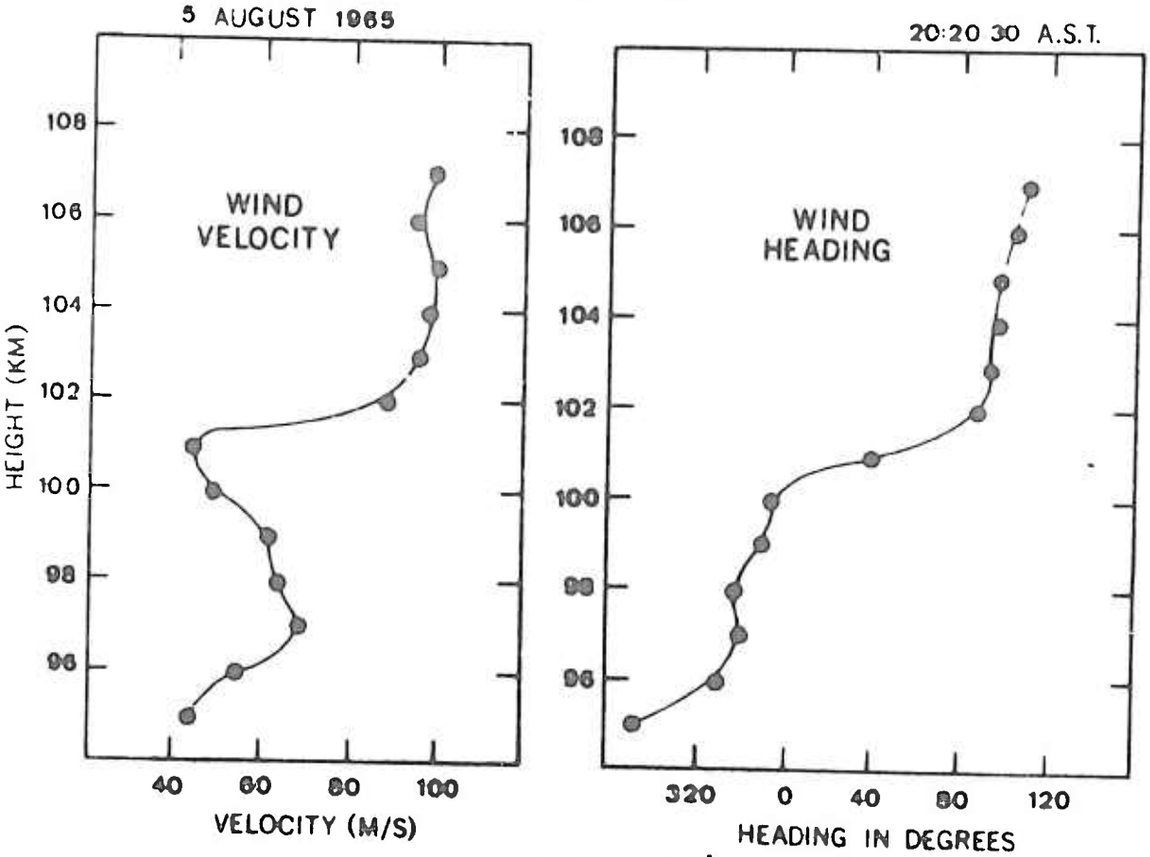

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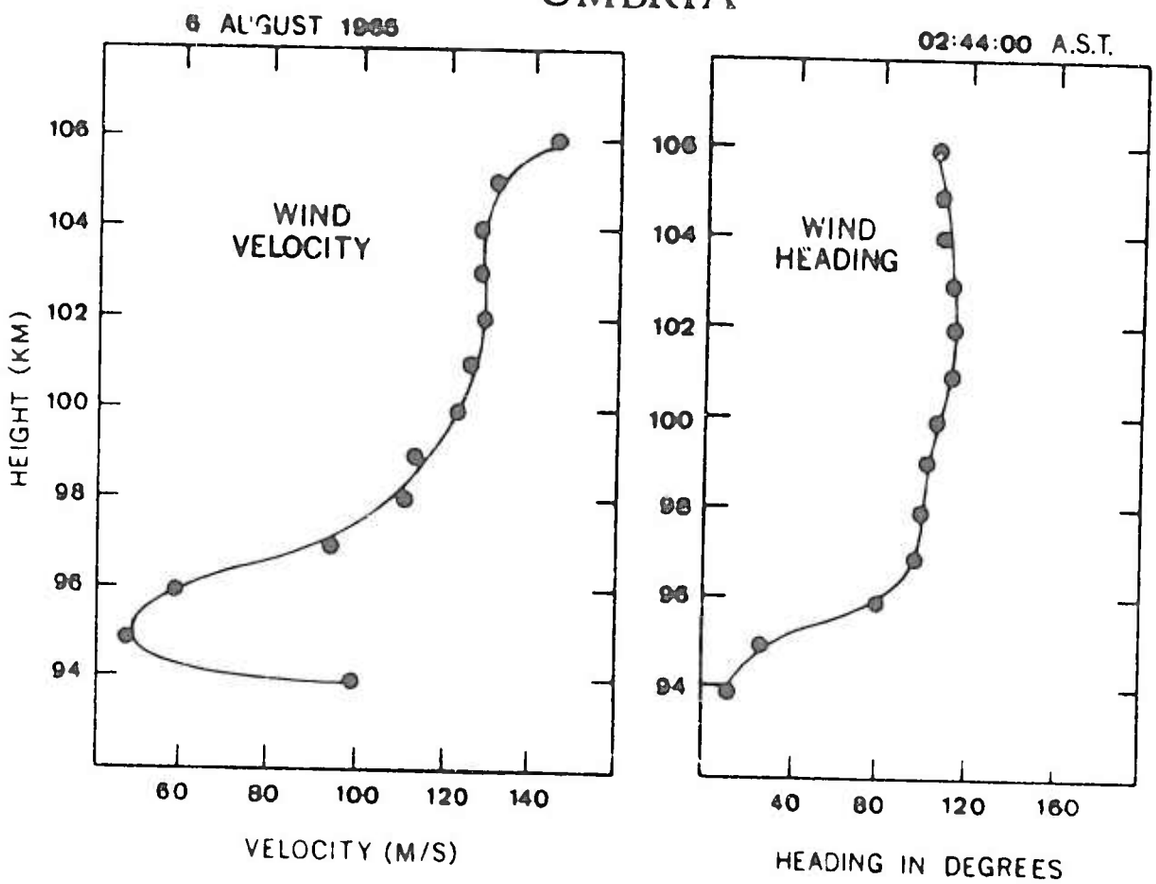

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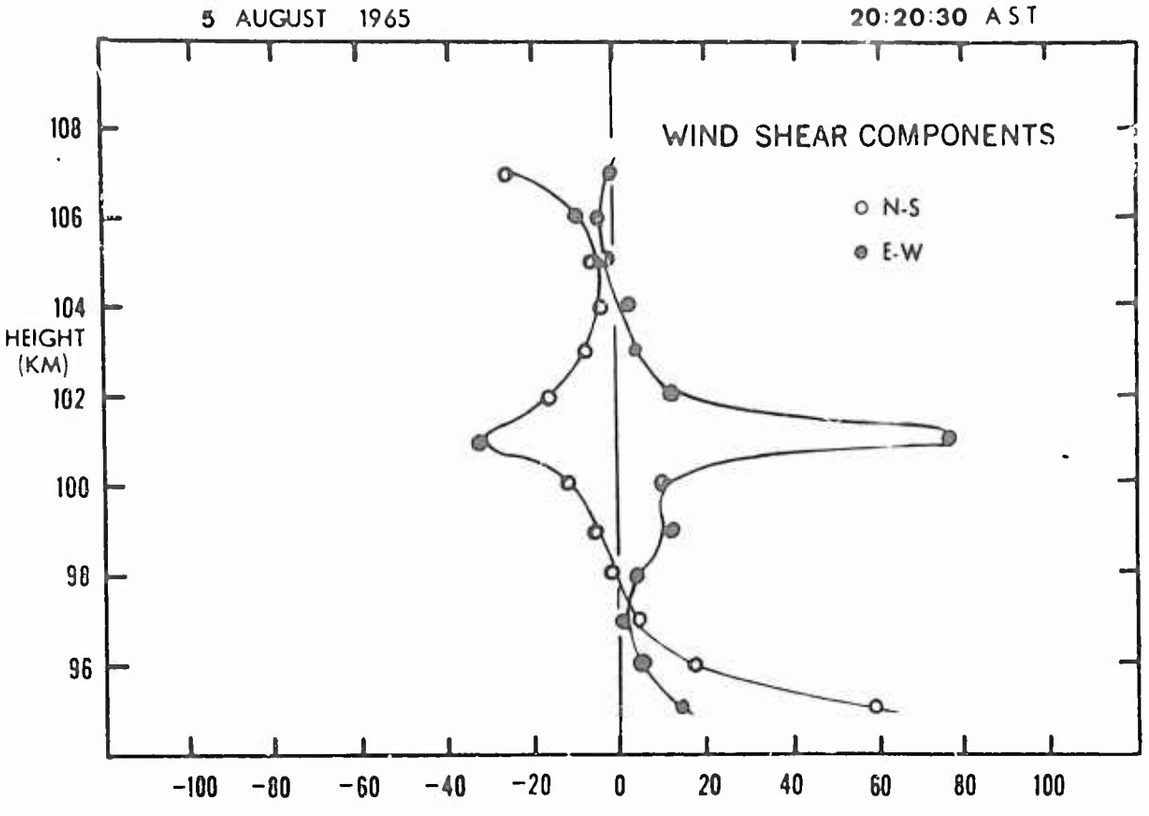

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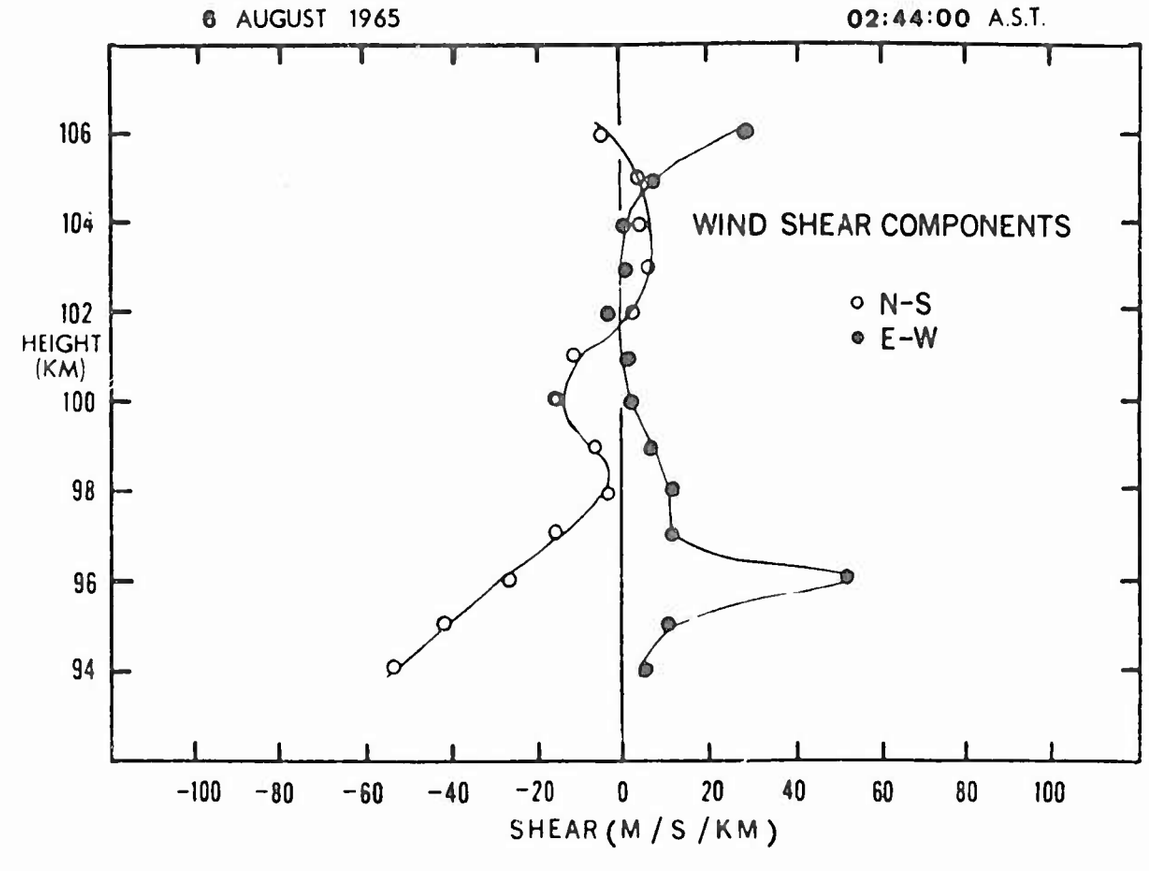

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13. ABSTRACT

During the period July 1964 to August 1965, eighteen luminous trails were produced between 87km and 121km by the release of tri-methyl aluminum from projectiles fired from a smoothbore sixteen-inch gun located on the West Indian island of Barbados (57.5°W, 13.1°N). These trails were photographed from neighboring islands and analyzed to yield wind profiles. Four such trails were produced in July 1964, five in March 1965, seven in June 1965, and two in August 1965. These were grouped in four one-trail-nights, five two-trail-nights, and one four-trail-night (3-4 June 1965). This report contains the tabulated wind data from all eighteen trails together with plots versus altitude of wind components, wind speed, wind heading, and wind shear components.

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